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Energy Technology Choices

SHAPING OUR FUTURE

J952-69

CONGRESS OF THE UNITED STATES
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Foreword

This assessment responds to a request by the House Committee on Energy and Commerce, the House Committee on Government Operations, and the Senate Committee on Energy and Natural Resources to provide an evaluation of the technical risks and opportunities facing our Nation's energy future.

The report provides a broad overview of energy choices facing the Nation. It is not an exhaustive analysis of any one technology; rather, it draws together the main themes of OTA reports from the past 16 years, and other documents, into an outline of the main directions the country could follow. We hope that the report will be used as a "roadmap," not an encyclopedia. It reviews options for increasing energy supply and using energy more efficiently in the face of resource constraints and the contrasting goals the Nation faces. It then analyzes packages of options that would be appropriate to meet national objectives. There is an old Chinese proverb that is appropriate to U.S. energy strategy: "If we don't change direction, we're very likely to end up where we're headed."

OTA appreciates the invaluable assistance provided by the project's advisory panel and reviewers during the course of this study.

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NOTE: OTA appreciates and is grateful for the valuable assistance and thoughtful critiques provided by the advisory panel members. The panel does not, however, necessarily approve, disapprove, or endorse this report. OTA assumes full responsibility for the report and the accuracy of its contents.

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Overview

The energy crisis of the early seventies has evolved into a more complex and subtle national situation that still entails major dangers. Some fuels, gasoline in particular, are actually cheaper now in real terms, and none shows any signs of imminent resource constraints. Energy is used with far greater efficiency than 20 years ago and with less environmental damage per unit of consumption. However, the long-term problems of our growing energy use—accumulating environmental degradation, the national security costs of imported oil supplies, and a worsening trade imbalance from rising levels of oil imports—are as intractable as ever.

Improved technology is a major reason for the present lull in attention to energy. A vast number of options that improved overall energy efficiency allowed the economy to grow 39 percent from 1972 to 1985 with essentially no increase in energy consumption. New technology has also improved the production of oil and natural gas and the combustion of coal. Success in moderating demand and improving supply has led to the present situation of ample supplies at moderate cost. Technology can continue to provide new benefits in the future. Many more technologies for the conversion and use of energy are well along in the development process and can be expected to be cost competitive with further refinement or energy cost increases. Tables 1 and 2 show the technologies that are available or under development for greater efficiency or alternative energy sources.

The three greatest uncertainties facing energy policymakers are: how to assure a long-term supply of reasonably priced, convenient fuels, especially for transportation; how to protect the country against disruptions of petroleum imports; and how to mitigate emissions of carbon dioxide if global warming concerns require it. Just as energy itself is useful only insofar as it enables one to achieve some desired service, energy policy is important only in its contribution to the three fundamental national goals of a clean environment, healthy economy, and security. Some initiatives contribute to all three goals, while others have conflicting results.

Failure to address these uncertainties could have very serious implications eventually. All indications suggest that U.S. oil production is in an irreversible decline. Not only are imports almost certain to rise, but peaking production in petroleum fields in other countries indicates that an increasing share of production will be from the Middle East. If the instability of the last several decades continues in that region, it is likely that major disruptions of supply, possibly exceeding our ability to protect the economy against them, will occur. U.S. production of natural gas, the cleanest conventional fuel, may rise some, but it is likely that within a decade the lowest cost resources will be significantly depleted. Oil and gas supply almost two thirds of our energy demand, so the economic cost of price increases will be great unless alternative modes of production or substitutes are available. Failing to prepare for new environmental concerns could lead to extremely costly impacts if global warming develops into a major threat. Complacency on energy issues entails a major risk for the country on all counts—security, economic, and environmental.

High energy prices in the seventies and early eighties were largely responsible for the rapid development and implementation of energy saving technologies that reduced energy demand and led to today's relatively low energy prices. Conversely, these low prices, while good for the economy, are limiting further efficiency, resource exploration, and alternative fuel investments.

Energy investments, whether supply or demand, typically last for decades. Thus, the energy system is slow to change, and problems that are unlikely to be critical for 20 years or more will be far more difficult to manage then if not addressed now. These critical problems include responding to the threat of global climate change, securing affordable supplies of energy, and protecting against oil import disruptions.

There is not now, and probably never will be, any single energy option that will ideally solve our long-term requirements. All options entail some compromises. Opportunities to improve energy efficiency are closest to the ideal. Many cost-effective opportunities exist, even at today's energy prices. Such investments are generally environmentally beneficial because they reduce energy production and consumption, economically beneficial because they more nearly approach rational distribution of resources, and beneficial to security because they reduce petroleum imports. However, significant structural and behavioral barriers impede their implementation. Alternative energy sources (e.g.,

Table 1—Technologies Affecting Demand

Technology	Sector	Availability	Comments
Variable speed heat pump	Residential/commercial	C,N	Improves energy efficiency and provides more flexible control. Widely used in Japan. Increasing market share in United States.
Scroll-type compressors (heat pump/air conditioning)	Residential/commercial	C	Newer scroll-type compressors are 10 to 20 percent more efficient than reciprocating ones. Widely produced in Japan.
Thermally active heat pump	Residential/commercial	R	Could have significant impact in 10 to 20 years.
Low-emissive windows	Residential	C,R	Significant impact on reducing thermal energy loss in homes. Research needed on improving durability, lowering emittance, and reducing condensation.
Heat pump water heaters	Residential/commercial	C	Offers significant reduction in electricity use; premium cost. Commonly used in Scandinavia.
Alternative insulation materials	Residential	R	Needed to counter loss of chlorofluorocarbon-blown insulation. Now being developed and tested.
Refrigerator insulation	Residential	R	Greatest potential for appliance efficiency improvements. New products include vacuum insulation, compact vacuum insulation, and soft vacuum insulation.
Efficient lighting products	Residential/commercial	C,N,R	Combination of lighting options can cut commercial energy use significantly. Improved fluorescents, compact fluorescents, and electronic ballasts commercially available. Research and development continuing on improving phosphors.
Building energy management and control systems	Residential/commercial	C,N	Greatest potential for savings in the commercial sector. Advances in this technology have been continual.
Industrial process changes:			
—Separation	Industrial	C,N,R	Improvements in separation and control, and the use of membrane technology and solvent extraction could reduce energy use considerably.
—Catalytic reaction	Industrial	C,N,R	By increasing reaction rates, lower temperatures and pressures can be used that reduce heating and compression requirements. Discovery and use of new synthetic zeolites have contributed to energy efficiency gain in petroleum refining and chemicals industries.
—Computer control and sensors	Industrial	C,N	Improved monitoring and control optimizes conversion and distribution of energy. Potential savings range from 5 to 20 percent.
Advanced turbine:			
—Steam-injected gas turbine (STIG)	Industrial/utility	C,N	Currently used in cogeneration applications.
—Intercooling (ISTIG)	Industrial/utility	N	Has potential to raise efficiency to about 50 percent. May be better suited for utility applications; pilot-plant stage.
Electric motors	Industrial	C	Adjustable-speed drive and new high-efficiency motors account for about half of the total potential savings in U.S. motors.
2-stroke engine	Transportation	R	Holds promise for long term. Questions remain about ability of engine to comply with emissions standards.
Direct injection/adiabatic diesel	Transportation	C,R	Limited passenger car application in Europe; offers considerable efficiency improvements for both light-duty vehicles and heavy trucks. Questions remain regarding meeting more stringent emission standards.
Ultra-high bypass engines	Transportation	C	Can raise efficiency by about 20 percent but costs two times as much as current generation bypass engines.
Alternative fuels:			
—Alcohol fuels	Transportation	C,N,R	Use of methanol and ethanol should result in greater engine efficiency but costs are higher.
—Electricity	Transportation	R	Big greenhouse advantage if derived from nuclear or solar energy.

KEY: C = commercial; N = nearly commercial; R = research and development needed.

SOURCE: Office of Technology Assessment, 1991.

nuclear, renewables, synthetic fuel) have some advantages, but none will be cheap relative to current fossil fuels. Thus without major policy initiatives, our energy system is likely to maintain its high dependence on conventional fossil fuels for several decades, increasingly interfering with environmental and security goals and using more than the optimal amount of energy.

Table 2—Major Technologies for Energy Supply and Conversion

Technology	Availability	Comments
Oil		
Deepwater/arctic technologies	C,R	Existing technologies that are promising for deepwater areas include guyed and bouyant towers, tension leg platforms, and subsea production units. Advances in material and structural design critical; innovative maintenance and repair technologies important.
Enhanced oil recovery techniques	C,R	Widely adopted over the past two decades.
—thermal recovery		
—miscible flooding		
—chemical flooding		
Oil shale and tar sands	C,N	Uneconomic at present oil prices.
—Surface retorting		
—Modified in situ		
Natural gas		
—Hydraulic fracturing	C	Very complex process; not well understood although successful for some formations. Key to unlocking unconventional gas reserves.
Coal		
—Atmospheric fluidized-bed combustion (AFBC)	N,R	Small-scale units commercial. Utility-scale AFBC in demonstration stage. PFBC is less well developed; pilot-plant stage.
—Pressurized fluidized-bed combustion (PFBC)		
—Integrated gasification combined cycle (IGCC)	N	Demonstration stage. Primary advantages are its low emissions and high fuel efficiency.
—Flue-gas desulfurization (FGD)	C	Mature technology; considerable environmental advantages.
—Sorbent injection	C,N	Commercially available control technology. Can remove nitrogen oxides up to 90 percent.
—Staged combustion	R	Has potential to remove up to 80 percent of nitrogen oxides.
Nuclear		
—Advanced light water reactor	C	Incorporates safety and reliability features that could solve past problems; public acceptance uncertain.
—Modular high-temperature gas reactor (MHTGR)	N,R	Improvements to familiar technology; incorporates passive safety features; design of modular reactor completed.
—Power Reactor Inherently Safe Module (PRISM)	R	Conceptual designs expected to be completed this year.
Electricity		
—Combined cycle (CC)	C	Conventional CC is a mature technology; advanced CC is in demonstration stage.
—Intercooling Steam Injected Gas Turbine (ISTIG)	N	Pilot-plant stage.
—Fuel cells	R	Several types being developed. Fuels cells that use phosphoric acid as electrolytes are in demonstration stage. Molten carbonate and solid oxide are alternative electrolytes that are less developed. Late 1990s availability, at the earliest.
—Magnetohydrodynamics (MHD)	R	Difficult technical problems remain, especially for coal-fired MHD systems.
—Advanced batteries	R	Research and development needed in utility-scale batteries to improve lifetime cycles, operations maintenance costs. Promising batteries are advanced lead, zinc-chloride and high-temperature sodium-sulfur..
—Compressed air energy storage (CAES)	C	First U.S. plant (110-MW) to begin operation in 1991; owned and operated by Alabama Electric Cooperative, Inc.
Biomass		
—Thermal use	C	Use of biomass by utilities is usually uneconomical and impractical.
—Gasification	C	Anaerobic digestion used commercially when biomass costs are low enough. Methane production from biomass not yet competitive with conventional natural gas unless other factors considered.
—Production of biofuels	C,R	Research being done on wood-to-ethanol/methanol conversion processes. Could be demonstrated by 2000.

(Continued on next page)

Policies to address long-term energy concerns include a wide range of initiatives. Energy taxes can internalize costs, e.g., security or environmental damage otherwise not considered in decisions on appliance, automobile, and industrial process purchases. Financial mechanisms, e.g., subsidies, can target particularly favorable but otherwise uncompetitive (at current energy prices) investments. Regulation can apply standards to raise performance of automobiles, appliances and buildings, and control the conditions under which Federal lands are available for oil and gas exploration. Information programs can improve decisionmaking. Research, development, and demonstration can make available

Table 2—Major Technologies for Energy Supply and Conversion—Continued

Geothermal —Dual flash —Binary cycle	N	Single-flash system used extensively. Little commercial experience with dual flash. Binary cycle system may be available in 40 to 50 MWe range by 1995.
Solar thermal electric		
—Central receiver	R	Several plants built, including one in California; 30-MW plant in Jordan is major project today.
—Parabolic solar trough	C	Several commercial plants built in California; additional capacity planned appears to be marketable.
—Parabolic dishes	R	Testing being conducted in new materials and engines such as free-piston stirling engine.
Photovoltaic —Concentrator system —Flat-plate collector	N,R	Improvements needed to make photovoltaic cells economic in the bulk power market advances in microelectronics and semiconductors can make photovoltaics competitive with conventional power by 2010.
Wind power	C	Renewable source closest to achieving economic competitiveness in the bulk power market. Current average cost is 8 cents/kWh.
Ocean thermal energy conversion (OTEC)	R	Research focused on closed and open cycle systems; no commercial plants designed. Maybe competitive in 10 years for small islands where direct-generation power is used. Use of OTEC domestically for electric power is unlikely except for coastal areas around Gulf of Mexico and Hawaii.

KEY: C = commercial; N = nearly commercial; R = research and development needed.

SOURCE: Office of Technology Assessment, 1991.

new options. The Federal Government can contribute directly to ameliorating energy problems by taking advantage of highly cost-effective measures to reduce energy purchases for Federal facilities by at least 25 percent.

Initiatives generally could be aimed at improving the efficiency of use of energy and the supply of energy. This report contrasts a baseline scenario (no major initiatives or surprises) with five variations representing different paths the Nation could follow:

- emphasizing production of conventional fuels,
- improving efficiency of use to the economic optimum,
- minimizing the use of energy as far as is technologically possible,
- emphasizing renewable energy sources, and
- emphasizing nuclear energy.

Any of these scenarios could be the most appropriate path depending on the resolution of uncertainties over climate changes induced by the greenhouse effect, technological developments, and resource discoveries. Each scenario presents risks as well as opportunities. This report describes the choices available to policymakers and the implications of choosing one path versus another.

Chapter 1

Introduction: The Changing Context for Energy Technology Policy

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Chapter 1

Introduction: The Changing Context for Energy Technology Policy

In the 17 years since the Arab oil embargo of 1973-74, our perceptions of the role of energy in the United States and world economies have changed considerably. Throughout the 1970s, concern about energy price and availability spurred the development of a wide range of new energy supply and demand technologies. The dramatic increases in energy efficiency of the U.S. economy were second only to Japan's during that period. Those efficiency improvements coupled with the decontrol of oil and gas prices initiated during the late 1970s led to increases in supply and falling energy prices in the mid-1980s. The result is that current policy concerns about energy are not driven by the sense of urgency about price and availability typical of the 1970s, but rather by other factors such as environmental quality, international competitiveness, and national security.

In addition, our understanding of how energy is produced and used has matured significantly since the 1970s, and we are much better equipped to make systematic, long-term decisions about energy policy and its interactions with other social, economic, and environmental policy. Today, a comprehensive, strategic national energy policy cannot be viewed as an end in and of itself. Rather, its direction must come from broader and more fundamental national goals of economic health, environmental quality, and national security. Therefore, as we consider the steps necessary to articulate a national energy policy, it only makes sense to develop it in ways that support these three and other related goals.

Congress currently is considering the President's National Energy Strategy and a wide range of other energy-related legislative proposals. The various options reflected in these proposals must be weighed in the context of the three overarching goals noted above. This is difficult, since the goals can conflict. For example, increased reliance on coal could cut oil import dependence, but exacerbate problems of air pollution and global climate change. Nonetheless, some energy options support all three goals, particularly those that improve efficiency of production and use.

New energy technology has always been a cornerstone of our strategies for dealing with current and long-term energy policy issues. Such technologies hold promise for cleaner and more efficient energy use, safer and more efficient recovery of energy supplies, and a smooth transition to a postfossil fuel era. Indeed, after two decades of mixed experiences with new energy technology, we understand much better the role of new energy technology in energy policy. In this overview report we review a number of the long-term U.S. energy technology and policy trends, discuss their interaction and implications, and finally consider a range of strategic energy technology policy options. Further, we reflect on some of these experiences and examine the risks and opportunities offered by major energy supply and demand technology options.

OTA has examined new energy technologies for the Congress since 1975 (see table 1-1). This report, designed to be an overview of energy supply and demand, is drawn largely from past OTA reports. Hence, it is not an exhaustive analysis of any one factor. Rather, it tries to draw together the main thoughts of a whole series of OTA reports and other documents into a broad outline of the main directions the country could follow with energy. We expect the report will be used by Congress as a roadmap, not an encyclopedia.

THE ENERGY POLICY CONTEXT

Annual global energy use grew from about 18 quads (quadrillion British thermal units)—equivalent to about 800 million tons of coal or 8.5 million barrels of oil per day—to 333 quads from 1900 to 1989. Industrialized countries account for 70 percent of annual worldwide commercial energy consumption. Coal, oil, and natural gas combustion currently account for about 80 percent of this energy use, and these fuels will likely continue to dominate for another 50 years. Many developing countries still depend heavily on noncommercial fuels, e.g., wood, dung, and crop wastes, but as their economies develop, they increasingly incorporate fossil fuels,

Table 1-1—OTA Reports That Address Energy Technologies[a]

Energy and Materials Program:
- *Energy Efficiency in the Federal Government: Government by Good Example?* OTA-E-492 (May 1991).
- *Energy in Developing Countries*, OTA-E-486 (January 1991).
- *Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles*, OTA-E-364 (September 1990).
- *Energy Use and the U.S. Economy*, OTA-BP-E-57 (June 1990).
- *Physical Vulnerability of Electric Power Systems to Natural Disasters and Sabotage*, OTA-E-453 (June 1990).
- *High-Temperature Superconductivity in Perspective*, OTA-E-440 (April 1990).
- *Electric Power Wheeling and Dealing: Technological Considerations for Increasing Competition*, OTA-E-409 (May 1989).
- *Biological Effects of Power Frequency Fields Electric and Magnetic Fields—Background Paper*, OTA-BP-E-53 (May 1989).
- *Oil Production in the Arctic National Wildlife Refuge: The Technology and the Alaskan Oil Context*, OTA-E-394 (February 1989).
- *Starpower: The U.S. and the International Quest for Fusion Energy*, OTA-E-338 (October 1987).
- *U.S. Oil Production: The Effect of Low Oil Prices*, OTA-E-348 (September 1987).
- *New Electric Power Technologies: Problems and Prospects for the 1990s*, OTA-E-246 (July 1985).
- *U.S. Natural Gas Availability: Gas Supply Through the Year 2000*, OTA-E-245 (February 1985).
- *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*, OTA-E-243 (September 1984).
- *Nuclear Power in an Age of Uncertainty*, OTA-E-216 (February 1984).
- *Industrial Energy Use*, OTA-E-198 (June 1983).
- *Industrial and Commercial Cogeneration*, OTA-E-192 (February 1983).
- *Increased Automobile Fuel Efficiency and Synthetic Fuels*, OTA-E-185 (September 1982).
- *Energy Efficiency of Buildings in Cities*, OTA-E-168 (March 1982).
- *Solar Power Satellites*, OTA-E-144 (August 1981).
- *Nuclear Powerplant Standardization: Light Water Reactors*, OTA-E-134 (April 1981).
- *World Petroleum Availability: 1980-2000*, OTA-TM-E-5 (October 1980).
- *Energy from Biological Processes*, OTA-E-124 (September 1980).
- *An Assessment of Oil Shale Technologies*, OTA-M-118 (June 1980).
- *The Future of Liquefied Natural Gas Imports*, OTA-E-110 (March 1980).
- *Residential Energy Conservation*, OTA-E-92 (July 1979).
- *The Direct Use of Coal*, OTA-E-86 (April 1979).
- *Application of Solar Technology to Today's Energy Needs*, OTA-E-66 (September 1978).
- *Enhanced Oil Recovery Potential in the United States*, OTA-E-59 (January 1978).
- *Gas Potential From Devonian Shales of the Appalachian Basin*, OTA-E-57 (November 1977).
- *Analysis of the Proposed National Energy Plan*, OTA-E-51 (August 1977).
- *Nuclear Proliferation and Safeguards*, OTA-E-48 (June 1977).

Oceans and Environment Program:
- *Changing by Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (February, 1991).
- *Facing America's Trash: What Next for Municipal Solid Waste*, OTA-O-424 (October 1989).
- *Catching Our Breath: Next Steps for Reducing Urban Ozone*, OTA-O-412 (July 1989).
- *Oil and Gas Technologies for the Arctic and Deepwater*, OTA-O-270 (May 1985).
- *Acid Rain and Transported Air Pollutants: Implications for Public Policy*, OTA-O-204 (June 1984).

International Security and Commerce Program:
- *Energy Technology Transfer to China—A Technical Memorandum*, OTA-TM-ISC-30 (September 1985).
- *Technology and Soviet Energy Availability*, OTA-ISC-153 (November 1981).

[a] Available through the U.S. Government Printing Office, Washington, DC.

SOURCE: Office of Technology Assessment, 1991.

especially coal and oil, in their industrial and commercial sectors.[1]

he United States currently consumes about 81 quads of energy. Many analysts project that over 100 quads of total energy will be required by 2010, assuming moderate economic growth. The baseline scenario in this report, which includes noncommercial energy, increases from 84 quads in 1990 to 112 in 2015. The National Energy Strategy's Current Policy Base projects U.S. energy consumption will reach approximately 115 quad by 2010.[2] With no changes in policy, the sources of energy we use to fuel the economy are expected at that time to be very similar to what they are today: about 40-percent oil, 23 percent each for natural gas and coal, and 14-percent renewables and nuclear power.[3] Still, some important features of U.S. energy supply and demand balance are changing and, in turn, are changing the environment within which policy decisions will be made, especially decisions about technology.

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[1] See U.S. Congress, Office of Technology Assessment, *Energy in Developing Countries*, OTA-E-486 (Washington, DC: U.S. Government Printing Office, January 1991).

Various "national energy plans" have been initiated frequently since 1939 (see box 1-A), usually instigated by concerns over resource shortages. Perhaps the lesson to be learned from this repeated attention is that energy policy must be fundamentally grounded in long-term strategies but must also accommodate short-term perturbations. Oil price disruptions have been the major perturbations in recent years, such as the 1990 price increase stemming from the Persian Gulf crisis.

However, reducing vulnerability to oil supply shortages will require more than a large petroleum reserve. Without policy action, imports of oil are very likely to increase substantially. Increasing dependence on imports, especially those from unstable regions, will necessitate a gigantic and extremely expensive reserve to maintain present protection against an extended import supply disruption. Increasing efficiency and fuel flexibility in the transportation fleet, the sector most dependent on oil, will be increasingly attractive. These measures would also serve the vital goal of reducing air pollutant emissions. Far greater changes will be required if major carbon dioxide (CO_2) emissions reductions are required to minimize climate change. Major changes in energy systems require decades and steady commitment from political leaders, industry, and citizens, and planning now for such changes would be prudent.

If the United States wishes to succeed in easing oil import dependence, cutting emissions, and increasing energy productivity, we must establish long-term efficiency and supply goals, and stick to the plan to achieve those goals through periods of both crisis and calm and through periods of varying oil prices. During the past decade, steady supplies, easy efficiency gains, and a retreat in the price of oil seduced us into largely abandoning efforts to push research in energy efficiency and alternative supplies. The war in the Middle East generated concerns over energy security reminiscent of the 1970s. Nonetheless, as the current crisis passes, we may be once again beguiled into a false sense of energy complacency.

TRENDS SHAPING ENERGY POLICY AND TECHNOLOGY CHOICES

The trends that have significant implications for long-term energy policy choices are: 1) the declining energy intensity of the U.S. economy between the 1970s and mid-1980s, 2) the sharply increasing U.S. reliance on foreign sources of oil, 3) the changing structure of the electric utility industry, and 4) the changing relationship between energy and the environment. This section discusses these trends and three areas of particular interest for energy technology policy: nuclear power, renewable energy, and research and development.

Declining Energy Intensity

For many years most observers believed that energy use and the gross national product (GNP) were firmly linked, moving upward in lock step. We learned from the energy shocks of the 1970s, however, that ingenuity can substitute for supply when the price is right. In the 1970s as energy prices rose, consumers responded by shifting their market basket of purchases and by developing more efficient ways to provide energy services. The energy intensity of the economy, the energy consumed per unit of GNP produced, fell 2.5 percent per year between 1972 and 1985, most of which was due to improved efficiency (see figure 1-1). The other major factor was the changing structure of the U.S. economy (e.g., the decline in energy-intensive industries, replaced by energy-intensive imports). OTA addressed these issues in its 1990 background paper *Energy Use and the U.S. Economy*.

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[2] *National Energy Strategy: Powerful Ideas for America*, 1st ed. 1991/1992, DOE/S-0082P (Washington, DC: U.S. Government Printing Office, February 1991), p. C-9.

[3] See the U.S. Energy Information Administration, *Annual Energy Outlook 1990* (DOE/EIA-0383(90), Jan. 12, 1990.

Box 1-A—National Energy Strategy: A Historical Note

In 1939 President Franklin Roosevelt appointed a National Resources Planning Board to examine the Nation's resources policy options. The Board recommended Government support of research to promote "efficiency, economy, and shifts in demand to low-grade fuels" and that a "national energy resources policy" should be prepared that "would be more than a 'simple sum' of policies directed at specific fuels."[1]

Later efforts included: a refinement of the Board's recommendations in 1947 by President Truman's National Security Resources Board; Truman's Materials Policy Commission of 1950-52 (known as the Paley Commission after its Chairman, William S. Paley); President Eisenhower's 1955 Cabinet Advisory Committee on Energy Supplies and Resources Policy; the 1961 National Fuels and Energy Study commissioned by the U.S. Senate during President Kennedy's term; President Johnson's 1964 "Resources Policies for a Great Society: Report to the President by the Task Force on Natural Resources"; President Nixon's 1974 "Project Independence Blueprint"; President Ford's 1975 Energy Resources Council reflected in his omnibus proposal "Energy Independence Act of 1975"; President Carter's 1977 "National Energy Plan"; President Reagan's 1987 "Energy Security" report; and, of course most recently, President Bush's 1991 "National Energy Strategy (NES)."

The major stated goals of the NES are the following:

- encourage the adoption of cost-effective energy efficiency technologies in all sectors, including electricity generation;
- increase the use of renewable energy in electricity generation and the residential and commercial sectors;
- in the industrial sector, increase fuel flexibility and decrease waste generation, particularly by recycling wastes and increasing their use as process feedstock;
- in the transportation sector, expand the use of alternative fuels, accelerate the scrappage of older, less efficient automobiles, promote mass transit and ride sharing, and evaluate whether the corporate average fuel economy (CAFE) standards should be changed;
- reduce U.S. vulnerability to fossil-fuel supply disruptions by improving and implementing advanced oil recovery technology, increasing U.S. and global oil and natural gas production generally, and expanding stocks (a major focus of supply expansion will include increased outer continental shelf (OCS) and Arctic National Wildlife Refuge (ANWR) exploration and development);
- revive the growth of nuclear power by standardizing powerplant design, accelerating the introduction of advanced designs, reforming the powerplant licensing process to hasten the growth of new nuclear capacity, and site a permanent waste facility; and
- enhance Federal research and development to reduce oil use, increase oil supplies, and develop alternative fuels.

The above list of NES goals is not complete, but it represents the key elements of the plan. There have been disputes over the goals of the strategy, whether the policy approaches suggested in the document match these goals, and whether it offers a viable mix of demand control and supply enhancement options. These issues are for policymakers to resolve. For its part, the NES is a broad plan that promises to affect the way some of our most important economic, environmental, and national security policies develop in the coming years.

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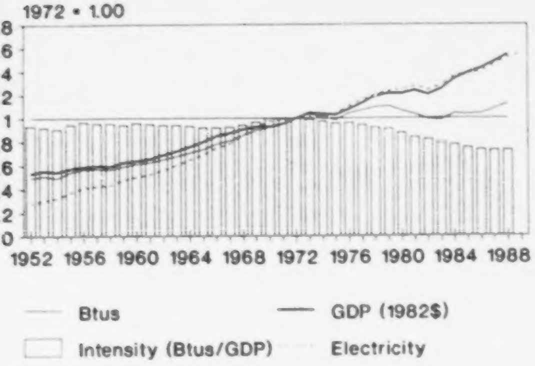
[1] *Energy Resources and National Policy*, Report of the Energy Resources Committee to the Natural Resources Committee, (Washington, DC: U.S. Government Printing Office, 1939); also summarized in C. Goodwin (ed.), *Energy Policy in Perspective* (Washington, DC: Brookings Institution, 1981).

Technology was at the heart of this changing intensity—technology ranging from dramatically increased efficiency in delivery of traditional energy services, e.g., heating, cooling, industrial processes, and transportation, to entirely new services that changed our lifestyles, e.g., improved airline travel, personal computers, and fax machines. In chapter 2 we examine the changing nature of U.S. energy demand and the implications of technology on demand growth and efficiency improvement.

Sharply Increasing Dependence on Foreign Oil

Today, the United States consumes about 17 million barrels of oil per day, 13 percent greater than in 1983. At the same time, the level of domestic oil production has declined, due to depletion of low-cost resources and a lack of new discoveries. The net result is that imports rose from about one-third of total U.S. consumption in 1983 to nearly 45 percent

Figure 1-1—Index of U.S. GDP, Energy Intensity, Energy Use, and Electricity Use



SOURCE: U.S. Energy Information Administration, *Monthly Energy Review, March 1991*, DOE/EIA-0035(91/03) (Washington DC: U.S. Government Printing Office, Mar. 28, 1991).

in 1990. This is addressed in OTA's 1987 report *U.S. Oil Production: The Effect of Low Oil Prices*, and in its 1989 report *Oil Production in the Arctic National Wildlife Refuge: The Technology and the Alaskan Oil Context*.

Moreover, the fraction of total imports coming from Persian Gulf nations has increased from about 4 percent of total U.S. consumption (10 percent of total U.S. oil imports) to over 10 percent (26 percent of current U.S. imports), as shown in figures 1-2 and 1-3. As the Soviet Union, the United States, and other non-OPEC (Organization of Petroleum Exporting Countries) nations deplete their lowest-cost oil reserves over the next decade or two, the geopolitics of energy will increasingly focus on the comparatively vast resources in the Middle East. OPEC[4] controls three-quarters of proved world crude-oil reserves, including all major recent additions. At least part of the rationale for Operation Desert Storm was due to our dependence on that region's oil reserves or, in President Bush's words, "U.S. economic interests there."

In this case, the disruption was minor because Iraq and Kuwait provided less than 5 percent of U.S. supply, and Saudi Arabia was willing and able to compensate for the shortfall. In the future, however, major U.S. supplies could be interrupted or lost, with limited replacements available only at great economic or political cost. For example, if the recent Gulf War had also interfered with Saudi Arabian oil exports, U.S. supply losses would have been much more severe.

Dependence on imported oil also strains our international balance of payments considerably. In the first half of 1990, the U.S. imported 24 billion dollars' worth of oil, an amount equal to 57 percent of our total trade deficit for that period. High levels of oil imports do not by themselves lead to poor trade balances (Japan is one counter example), but such a high cost warrants strenuous efforts to ensure that oil is used with optimal efficiency. Many opportunities for increasing energy efficiency are noted in this report.

In addition, even in peacetime, the Pentagon spends many billions of dollars to protect oil supplies. With the conclusion of Operation Desert Storm, military expenditures linked to preserving oil supplies rose substantially. Rebuilding the war-torn countries of the Middle East may also prove very expensive. These are part of the costs of imported oil, even though they are not reflected in the price of oil and oil products.

Some characteristics of today's U.S. oil use, domestic supply, and import dependence are similar to those of the 1970s, e.g., the almost total reliance of our transportation sector on oil. Other features, however, have evolved considerably, including the efficiency of oil use in many industries, lower dependence of electric utilities on oil, diversification of world oil supplies (albeit not reserves), international agreements on oil sharing, the strategic petroleum reserve, changes in energy regulation (e.g., removal of oil price controls and restrictions on natural gas use), and the emergence of active spot and futures markets for oil supply. (See box 1-B.)

All of these changes have had an effect on the possible future of oil use and of U.S. dependence on imported oil. Despite these changes, the U.S. economy is and will be increasingly dependent on foreign supplies of oil for years to come. This dependence will continue to threaten our national security, and it promises to continue aggravating our balance of payments.

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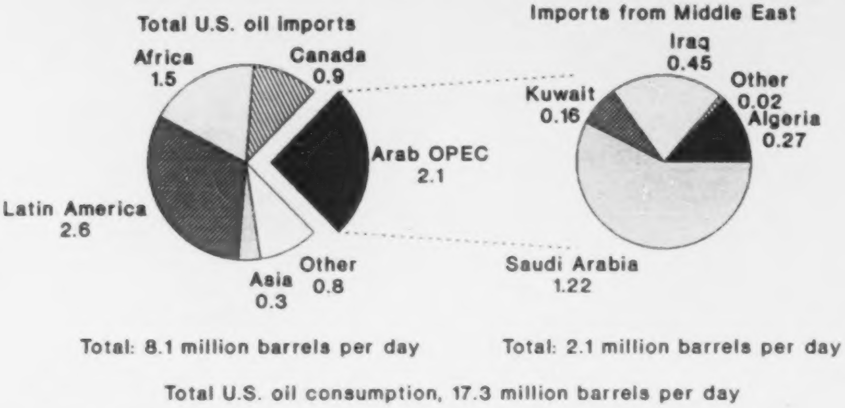
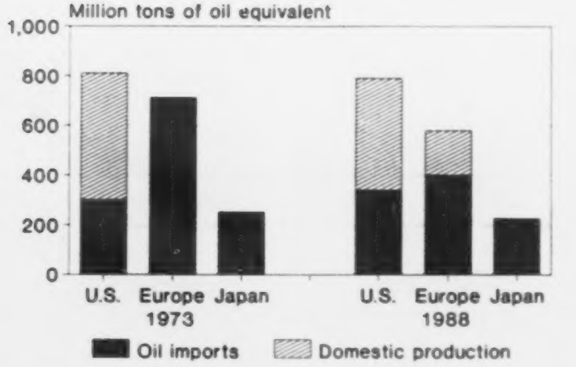
[4] The members of OPEC include: Saudi Arabia, Iraq, Kuwait, Qatar, Venezuela, Iran, Libya, United Arab Emirates, Algeria, Ecuador, Gabon, Indonesia, and Nigeria.

Figure 1-2—U.S. Oil Imports, 1989 (millions of barrels per day)



SOURCE: U.S. Central Intelligence Agency, *International Energy Statistical Review*, 1990.

Figure 1-3—Total Oil Use and Imports U.S., Europe, and Japan, 1973 and 1988



SOURCE: U.S. Energy Information Administration, *International Energy Annual 1988*, DOE/EIA-0219(88) (Washington DC: U.S. Government Printing Office, Nov. 7, 1989).

Change in the Electric Utility Industry

The U.S. electric utility industry has weathered dramatic change in the last two decades. A dominant factor precipitating change in the 1970s was the price of fuel. On average, utilities had to pay over 200 percent more in real dollars for fossil fuels in 1984 than in 1972. In addition, the construction costs of new powerplants, particularly nuclear, rose dramatically due to a combination of factors: increased attention to environmental and safety issues (contributing to extended construction leadtimes and added equipment costs), high inflation and interest rates, delays in construction schedules and, in some cases, poor management. The higher costs of fuel and capital meant higher electricity costs, and utilities sought higher rates for the first time in decades. Most utilities (and industry analysts) seriously underestimated the price elasticity of electricity demand. Demand growth plummeted from 7 percent a year in the early 1970s to less than 2.5 percent by the end of the decade. Though consumers began using electricity more frugally, powerplant construction schedules did not shrink accordingly, and an oversupply of capacity resulted, adding to utilities' problems.

The outlook for the electricity generating industry has improved. The demand for electricity has risen substantially (see figure 1-4) and fuel costs have stabilized. However, the industry continues to change, as evidenced by:

- the emergence of an independent power producer industry and other signs of increasing competition in the industry (e.g., a number of major mergers and acquisitions and proposals to modify the Public Utility Holding Company Act);
- the accelerating trends of least-cost planning, integrated resource planning, and other innovative State regulation;
- increased attention to demand-side management and investment;
- the restoration of natural gas as an important fuel for electric power generation;

Box 1-B—Changes in U.S. Oil Supply and Demand Since 1973

Energy Efficiency of the U.S. Economy: As noted above, energy efficiency has risen considerably in all sectors of the economy, often through permanent structural changes driven by economics. Changes include improvements in both the efficiency and flexibility of energy-using technologies.[1] For example, automobile, industrial boiler, and electric powerplant fuel efficiency have all improved substantially. Nonetheless, many opportunities still remain, although they may be more difficult to secure without higher energy prices.[2]

Strategic Petroleum Reserve (SPR): The United States now has an SPR containing approximately 585 million barrels of crude oil,[3] the equivalent of about 100 days of oil imports at current levels. Similarly, Europe and Japan have also added to their strategic storage, although not to the same extent as the United States.

Diversified World Oil Production: Sources of world oil production have become substantially more diversified since the 1970s, with the OPEC share of the world oil market declining from 60 percent in 1979 to approximately 35 percent today. For several years, at least, no single country or cohesive group of countries will be able to control as large a share of the world market as was possible previously. Eventually, however, OPEC will regain substantial market share, especially as U.S. and Soviet production declines.

Concentrated World Oil Reserves: Despite diversified world oil production, nearly all recent reserve additions have been in the Middle East. Moreover, the costs of exploration, field development, and production in the Middle East remain considerably below that of other oil producing regions and are likely to remain so.

Increased Flexibility of Oil Use: A considerable portion of any increase in oil consumption both in the United States and in the remainder of the free world is reversible. For example, much of the increase in U.S. oil use in transportation over the last decade involves changes in consumer behavior, e.g., increased driving, that could be quickly reversed in case of an oil shortage or large price increase. In the industrial sector, many of the shifts to oil for a boiler fuel can be rapidly reversed with a shift back to coal or natural gas. Similarly, in the electric utility sector, a substantial portion of any increased oil use is likely to involve the use of existing oil-fired generating capacity—removed from baseline service when oil prices rose in the 1970s—in favor of coal, gas, or even nuclear plants. As long as the industry retains excess generating capacity, this use can be readily reversed, and even with diminishing capacity, fuel switching capability is much more common now than in the 1970s.

New International Oil Trading Mechanisms: Most of the world's oil is now traded through spot markets, in contrast to the long-term contracts of the 1970s. Coupled with an active futures market, this new oil trading situation makes single country embargoes, which could never be airtight even in the past, still less of a threat.

Increased Availability of Natural Gas: The widespread concern in the 1970s about scarcity of natural gas resources has given way to aggressive increases in natural gas use, especially in industry, commercial space heating, and electric power generation.

International Agreements on Oil Sharing: The International Energy Agency (IEA) was created in the 1970s in part to coordinate maintenance of strategic stocks of petroleum as well as plans for demand reduction for use during an emergency. In early 1991, the IEA governing board voted to draw on 2 billion barrels of crude oil reserves to avert any shortages caused by the Middle East war.

Changed Energy Regulation: United States oil prices are no longer controlled as they were during the 1970s. In the event of a new price increase, the market forces that act to reduce demand and increase supply will be felt in full. In addition, restrictions on the use of natural gas in electric utility boilers and other industrial applications are no longer in effect. These and other regulations, e.g., the national 55 miles-per-hour speed limit, could be reimposed in case of crisis, but the overall trend has been toward letting the market control the allocation of energy.

Changing Economic Structure: Over the last decade, the steady decline in energy intensity (energy consumed per unit of gross domestic product produced) accelerated in response not only to the influence of improving energy efficiency, as noted above, but also to changing patterns of consumer demand, a shifting balance of imports and exports of both energy and nonenergy goods, and the changing market basket of goods produced in the United States. These changes have, as a consequence, had an effect on the future oil replacement potential in the U.S. economy.

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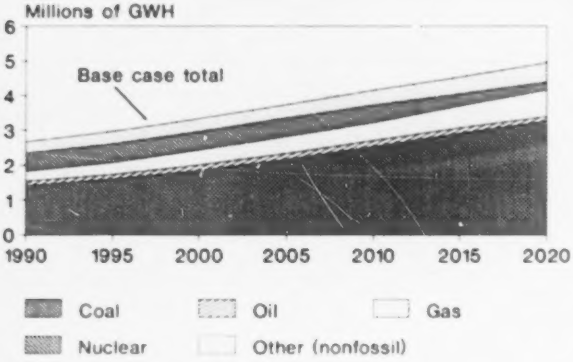
[1] See U.S. Congress, Office of Technology Assessment, *Technology and the American Economic Transition: Choices for the Future*, OTA-TET-283 (Washington, DC: U.S. Government Printing Office, May 1988).

[2] OTA is examining this in much more depth in its ongoing assessment *U.S. Energy Efficiency: Past Trends and Future Opportunities*.

[3] Energy Information Administration, *Monthly Energy Review, February 1991*, DOE/EIA-0035(91/02), Feb. 25, 1991, p. 41.

Figure 1-4—U.S. Electricity Consumption, 1989 Base Case to 2020



SOURCE. Gas Research Institute Baseline for 1989.

- the anticipated effects of the Clean Air Act Amendments of 1991; and
- the long-term implications of policies concerning global climate change.

These changes are certain to affect future technology choices, operating characteristics, and regulatory policy. Box 1-C summarizes these changes in more detail.

Changing Environmental Dimensions of Energy Policy

Much of the energy policy enacted in the last decade has actually been driven by environmental concerns. Moreover, the impetus for accelerated development of some new energy technologies has been spurred primarily by environmental concerns, e.g., clean coal technologies such as gasifiers and alternative transportation fuels such as methanol. The evolution of environmental regulation in air, water, nuclear waste, surface mining, oil exploration and development, and other areas will strongly influence the evolution of energy supply and demand technologies in the coming decades. These issues are discussed in chapters 2 and 3.

The Nuclear Dilemma

In much of the industrialized world, including the United States, nuclear power is playing an increasing role in electric power generation, while simultaneously encountering serious obstacles to further development. In the United States, nuclear power provides almost 20 percent of our electricity, but the last viable order for a new nuclear powerplant was made in 1974.

In 1984 OTA delivered its report *Nuclear Power in an Age of Uncertainty*, which addressed the issues involved in keeping nuclear as an option, and concluded: **"Without significant changes in the technology, management, and level of public acceptance, nuclear power in the United States is unlikely to be expanded in this century beyond the reactors already under construction."** The conclusion is still valid today, but increasing concern over CO_2 emissions, which nuclear can help control, greatly increases the importance of resolving the issues.

Most of the major issues besetting the nuclear option are related to the technology:

- Are reactors sufficiently safe?
- Can they be built, operated and eventually decommissioned economically?
- Can nuclear waste be disposed of safely?
- Does nuclear power significantly increase the risk of the spread of nuclear weapons?

Several technological approaches to these issues, e.g., improved safety and economics, are discussed in chapters 3 and 4. Whether these efforts will be enough to improve public opinion is still uncertain.

Renewable Energy Technology

Some renewable energy technologies are already mature, e.g., hydropower, solar collectors, and passive solar design features. At the other extreme, solar power satellites would require decades of research and development (R&D). Some renewable technologies, e.g., photovoltaics and wind, are commercially available but are competitive with traditional fuels only for specific sites and can make only a limited contribution at present. Finally, other renewable technologies, e.g., solar thermal electric power and some advanced biomass technologies (including biomass-based synthetic liquid and gaseous fuels), have few commercial applications, but have great potential for improved cost and performance.

The technologies in the latter two categories—those with some commercial applications and those that are near-commercial, waiting for escalations in fossil fuel prices, continued technical development, and possible public policy changes—could potentially be in a position for significant commercial

Box 1-C—The Changing U.S. Electric Utility Industry

Uncertainty in Electricity Demand Growth: A crucial legacy of the 1970s and 1980s is the uncertainty in future electricity demand growth. The experience of the 1970s reveals that users of electricity are able to alter the quantity they use much more quickly than utilities can accommodate these changes with corresponding changes in generating capacity. The current range of published forecasts is about 1- to 4-percent average annual peak demand growth. This translates to a range of around a 30-gigawatt (GW) surplus of electric generating capacity to a 280-GW shortfall of capacity beyond currently planned additions and retirements by 2010. Even within individual forecasts, the range of uncertainty is typically very high. For example, the North American Electric Reliability Council projects that total electricity demand (summer peak demand) for 1999 with an 80-percent probability band will be 128,000 megawatts (MW)—amounting to a 100-GW shortfall or about a 28-GW surplus at the ends of the uncertainty range compared to currently planned additions and retirements.[1]

Shifting Electricity Markets: Compounding the demand uncertainty is the changing nature of demand. For example, in the residential sector there is saturation in some markets, e.g., many major appliances in homes, but there is also intense competition between natural-gas-fired space heating and electric heat pumps. The future of industrial demand is clouded as some large industrial users of electricity are experiencing declines in domestic production due to foreign competition while others, like steel, are improving. At the same time, rapid growth continues in other areas, e.g., space conditioning for commercial buildings and electronic office equipment. Predicting the net impact of these offsetting trends, along with continued movement toward increased efficiency, has greatly complicated the job of forecasting demand.

Increasing Costs of Electricity Generation: Increased attention to environment and safety issues over the last two decades has contributed to both extending leadtimes in the siting, permitting, and construction of new powerplants as well as to rapidly rising per kilowatt costs of these plants, especially coal and nuclear plants. In the "old" days (1960s for the utility business) of steady demand growth, falling marginal costs (due largely to improving technology) and low interest rates, an excess of new capacity was not all that costly and demand growth would quickly erase the excess. Now, uncertainty about demand growth dominates. It is not only greater, but also more important, and overcommitting to new capacity can be very costly.

More Flexible Planning Strategies: Uncertainty has forced utilities to plan for contingencies. They now plan for a range of plausible future scenarios rather than committing to a fixed plan. When load growth exceeds expectations, as in New England and the Mid-Atlantic Regions in the 1980s, shorter leadtime resources such as demand-side management (DSM) and combustion turbines are called upon. Also, some utilities are performing pre-construction planning and site preparation to reduce the time required to construct new units, in case demand grows rapidly.

More Technology Options: Utilities now seek technology that comes in smaller unit sizes that can much more flexibly meet uncertain demand growth. The uncertainty in load growth provides the opportunity to dramatically expand the role of DSM and smaller-scale, shorter leadtime generating technologies (e.g., natural gas-fired combined cycle units) in utility resource plans. In addition, the prospects for advanced coal technologies renewables are expanding, although their commercial penetration is being slowed by low fuel prices.

Changing Regulatory Structure: In 1978, the Public Utility Regulatory Policies Act (PURPA) amended the 1935 Federal Power Act to require electric utilities to purchase electricity from nonutility generating facilities that met standards established by the Federal Energy Regulatory Commission, i.e., cogenerators and small power producers termed qualifying facilities (QFs). PURPA was the first major Federal move to open the electric utility market to nonutilities. Opening electricity markets to increased competition was the focus of the policy debates in the electric utility industry throughout most of the 1980s. Until the late 1980s, however, competition played a minor role in electricity markets, with the notable exception of facilities operated under PURPA.

In the last several years, as utilities resolved technical concerns and gained more experience with nonutility generation through PURPA, State regulators established mechanisms to foster competition for new generating facilities, e.g., competitive bidding by independent nonutility power producers. Also until recently, most State regulation of electric utilities has in effect linked utility profits with the amount of electricity sold, discouraging utilities from motivating their customers or undertaking themselves cost-effective energy conservation options. Some State utility commissions are establishing integrated resource planning programs that allow utilities to profit from investing in energy conservation programs or promoting such programs by their customers.

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[1] North American Electric Reliabilitty Council, *1990 Electricity Supply & Demand for 1990-1999*, November 1990, p. 15.

application in the 1990s, but not at their current rate of technical development. For most renewables, the goal of research, development, and demonstration (RD&D) remains to reduce costs and increase performance so that these technologies can compete with the conventional energy sources under traditional terms.[5] Performance improvements, cost reduction, and resolution of uncertainties will all occur, but the rate at which these improvements occur will depend on sustained progress in RD&D and survival of an industry infrastructure. Moreover, as we gain experience with some renewables, we learn more about their own adverse environmental impacts, e.g., hydropower's aquatic ecosystems impact and wind energy's noise impacts.

Technology Research, Development, and Demonstration

Many technologies are available to supply energy or improve its use. Many more will be available as R&D programs are pursued. Some of these were noted above. A continued Federal presence in RD&D is essential to sustain energy technology development. OTA's 1985 report *New Electric Power Technologies: Problems and Prospects for the 1990s* identified a number of alternative policy options aimed at accelerating the commercial availability of technologies potentially useful in the electric power industry. These options apply in many respects to other new energy technologies as well since they focus on reducing cost, improving performance, and resolving uncertainty in both cost and performance. The major policy questions are on the level and direction of the Federal programs, and whether it should include commercialization initiatives.

The appropriate level and direction of RD&D depends on the perceived need for new technology. Economically, it is likely that a significantly larger RD&D program could be justified even under current, noncrisis conditions. New technology can save money, and the energy system is so large that even a small saving can pay back a large investment in R&D. If a major reduction of CO_2 emissions proves necessary, the RD&D program should be much larger. Every available efficiency, nuclear, and renewable energy option would be necessary, and most of these could be made available sooner with greater funding. These technologies are discussed in the following chapters.

Under less drastic conditions, the current level may be adequate, but shifts in emphasis among programs may be considered, depending on the results desired. The scenarios in chapter 4 assemble the technologies according to the conditions under which they would be most useful.

The current U.S. R&D strategy assumes that private industry will commercialize new energy technologies as they become viable. This strategy reflects the desire to avoid repeating premature commercialization failures, e.g., the Synthetic Fuels Corporation. However, it is legitimate to ask if this strategy may not be an overreaction to past failures, especially since the Federal Government may have a greater interest in promoting particular technologies than has private industry. In particular, private industry is not traditionally expected to include environmental concerns or nonmarket considerations of foreign policy and national security in corporate investment decisions. The Federal Government plays the principal role in encouraging and sponsoring technology development for such reasons. Of particular concern is assuring availability of liquid fuels as substitutes for oil and improving efficiency in the use of oil, on which virtually our entire transportation system relies. Another concern is finding more environmentally acceptable ways to provide energy services. The current period of low and stable world oil prices, which may well continue through the 1990s, provides a window of opportunity for developing supply substitutes and new, more efficient end-use technologies, to ensure commercial availability of these technologies in the 1990s.

CANDIDATE ENERGY POLICY GOALS TO REFLECT A NATIONAL ENERGY STRATEGY

Long-term energy policy goals must be responsive to the three long-term policy interests of *economic health*, *environmental quality*, and *national security* because energy's importance is mostly gauged by its ability to sustain such societal goals. The following prospective energy goals are aimed at this end.

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[5] Competition under traditional terms neglects to account adequately for the pollution and other externalities of energy production and use. For renewables to compete better in our current economic and regulatory system, further RD&D will be needed. Of course, if externalities such as environmental damage were captured in the price system, renewable technologies would at present be far more competitive with conventional fossil and nuclear sources.

Limit Oil Import Dependence and Diversify Supply Sources

Candidate goals to reflect a strategy of limiting oil import vulnerability are: 1) to limit overall oil imports to a fraction of total U.S. oil use (perhaps 50 percent); and 2) to diversify sources of world oil production and, therefore, U.S. sources of imports to regions of the world outside the Middle East, where such imports can be aligned with other U.S. policy interests. The latter includes the transfer of technology to the Soviet Union to improve oil production from depleted wells. Such transfers were discussed in 1981 in the OTA report *Technology & Soviet Energy Availability*. Since these decisions are primarily political not technological, this report focuses on the first goal.

Supply mechanisms to limit oil imports include sustaining or slowing the decline in domestic oil production, and developing and producing alternative transportation fuels. Demand and fuel-switching mechanisms include improved efficiency of use in all sectors and shifting industrial, residential, and commercial oil use to other sources, e.g., natural gas or electricity.

All of these options imply commercial development of new technologies. Some technology options, however, may lead to policy conflicts. For example, the current strategy for developing alternative transportation fuels is driven by the need to improve air quality in urban areas. Likely options include alcohol fuels (methanol and ethanol), compressed natural gas, and electricity. If methanol produced from natural gas proves to be the most practical and cost-effective option, most of the additional demand would have to be met with imports, because U.S. production is unlikely to increase sufficiently. The world natural gas market is more diversified than is oil, but the most inexpensive and plentiful supplies are, like oil, located in the Middle East.

Improve Energy Efficiency

OTA's studies over the past decade have consistently shown that energy efficiency is an essential cornerstone to a comprehensive energy policy framework. About two-thirds of the growing U.S. energy productivity of the last decade is attributable to improving energy efficiency. Efficiency gains have also affected electricity use, which historically has grown faster than the economy but, in the last decade, has fallen back to the same rate of change as GNP. Moreover, these efficiency gains generally have been realized with net cost savings and without sacrifice of comfort or dollars. Considerable future energy efficiency gains are still possible in all sectors of the economy using existing technology. Even greater cost savings and efficiency gains will be possible with technologies under current R&D. **An efficiency goal of sustained improvement of 2 percent per year[6] is realistic for the United States.** With more vigorous research on energy efficiency, coupled with investment and policy leadership, this goal can be met or exceeded—and with options that are no more costly than pursuing the supply-side path. Moreover, pursuing such a goal supports all three policy interests of economic health, environmental quality, and energy security.

Improve Environmental Quality

A responsible energy policy should complement as much as possible a responsible environmental policy. Clearly there are some activities that can spur our economy and enhance national security but run counter to environmental goals (e.g., aggressively pursuing a long-term strategy of alternative transportation fuels such as methanol, but allowing the feedstock for these fuels to be coal rather than biomass). But those activities should be seriously considered only if we have exhausted other options that more generally support all three goals (e.g., developing economical fuel cells that burn biomass-derived fuel efficiently and cleanly to power automobiles).

With a wealth of existing or in some cases near-commercial technology, we see no reason why existing environmental goals need to be significantly compromised to achieve energy goals. Energy and environmental goals are, of course, closely linked and, therefore, neither energy nor environmental policies should be developed, assessed, or changed in isolation.

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[6] Energy efficiency is easy to measure for individual products or processes but difficult to define in the aggregate. Total energy use divided by GNP yields the energy *intensity* of the economy, but shifts in the energy intensity may signal changes in the mix of the economy or the goods and services involved that do not necessarily mean changes in efficiency. If the economy maintains its characteristics, then intensity and efficiency are identical. In that case, the goal could be met by, e.g., a 2-percent growth in GNP with constant energy demand. If the economic trends of the past decade are maintained, i.e., energy-intensive industries such as steel declining while less intensive service industries grow, then energy intensity would have to decline by 3 percent to show a 2-percent gain in efficiency; see U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy*, OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990).

Implications of Goals on U.S. Oil Import Dependence

In chapter 4 we consider several aggressive strategies in supply, efficiency, and fuel shifting for reducing U.S. oil import dependence. The options include improving efficiency of energy use in transportation, industry, and buildings; increasing domestic production of oil; and encouraging the use of alternative fuels.

It is clear that vigorous and sustained efforts would be required to stabilize oil import dependence over the next several decades—even at a level of 50 percent. The biggest opportunities for this lie on the demand side. Fortunately, these can provide important new economic activity and strength at home. To the extent that we improve efficiency cost-effectively, supplies will last longer, environmental problems will be eased, and international tensions lessened. But improved efficiency is unlikely to be enough. The opportunities on the supply side, e.g., enhanced domestic production in the lower 48 States, offshore, and in Alaska, are more modest than increased demand efficiency, but still potentially important. And, as noted earlier, there are opportunities for using alternative transportation fuels, e.g., methanol and electricity. These fuels have extensive long-term implications, however. The oil replacement potential must be weighed against the economic, energy, and environmental costs associated with producing and using these fuels. Last fall OTA released its report *Replacing Gasoline: Alternatives for Light-Duty Vehicles*, which addresses this subject in more depth.

The pacing and mix of all the efforts described above are very important. Much can be done to counterbalance the ominous projected growth of oil import dependence, but even with relatively heroic measures the United States is likely to face a future of high dependence on imports. We are *not* as optimistic here as the administration's position in the National Energy Strategy. In particular, the National Energy Strategy projects that the implementation of its domestic oil production policies along with assumed increases in the use of alternative fuels will lower net crude imports to just under 41 percent of domestic demand by 2010.[7] As this National Energy Strategy projection of slackening import dependence is largely based on assumptions about domestic production increases from enhanced oil recovery technologies and yet unverified Arctic National Wildlife Refuge reserves, OTA considers this drop in the level of oil imports improbable and optimistic. Coupled with aggressive efficiency efforts, however, this projection would appear more reasonable. In the following chapters we outline the technology dimensions inherent in alternative strategies for reducing import dependence.

Linking U.S. Energy Strategy to Global Climate Concerns

For decades we assumed that fossil fuels could supply our energy needs for several more centuries. Our only serious "bet-hedging" to fossil fuels has been nuclear power—fission and fusion. While the latter goal remains frustrating and elusive, the former now accounts for 20 percent of U.S. electricity, or about 8 percent of our total primary energy budget. Other nonfossil (mostly hydroelectric and biomass) fuels add another 8 percent, so our present nonfossil energy budget is about 16 percent. But the nuclear fission power enterprise, as noted earlier, is in deep trouble. Our long-term efforts to harness solar energy have been inadequate to produce options that could be widely deployed at reasonable cost.

The rising specter of air pollution and climate change creates added concerns for continued reliance on fossil fuels. This means that renewed efforts to develop solar and nuclear power (fission and fusion) must be considered. Developing and preserving nuclear and solar options are certainly possible, but they will require long-term commitments of research, development, and investment. The OTA report *Changing by Degrees: Steps To Reduce Greenhouse Gas Emissions* outlines the technical steps that would be necessary to reduce U.S. carbon dioxide emissions.

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[7] In its integrated analysis of proposed policy options, the National Energy Strategy projects that total U.S. oil demand in 2010 will amount to 19.2 million barrels/day (MMB/D), while net imports in that year will be only 7.8 MMB/D. *National Energy Strategy*, op. cit., footnote 2, pp. C22-C23.

CONCLUSIONS

In addition to providing for contingencies and interruptions, a priority policy consideration is to decide whether it is wise to constrain the growing U.S. appetite for imported oil. Another key policy avenue is the need to make an explicit commitment to a smooth, multidecade transition to the postfossil fuel age as well as an era of constantly advancing energy productivity. If we want to accomplish such goals at minimum cost, it will take more than a decade from whenever we start to stabilize our dependence on imported oil, and it will take a half-century or more to get beyond fossil fuels. **Our long-term economic, environmental, and national security future hangs on such transitions, and the specter of global warming could greatly foreshorten the time we once thought we could depend on coal and other carbon-rich fossil fuels.** The relationships among the long-term goals of economy, environment, and security provide some important guiding principles—principles from which a systematic, integrated, and comprehensive energy strategy, which is responsive to all three goals, can logically follow. In the following chapters we examine the technology dimensions of affecting these transitions.

Chapter 2

Technologies Affecting Demand

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Chapter 2

Technologies Affecting Demand

After the oil crises of the 1970s, the United States made tremendous strides in improving energy efficiency. This was accomplished by technological advances in energy-using equipment and production processes and structural shifts in the economy toward less energy-intensive products and services. By the mid-1980s, however, stable oil prices and supplies shifted the Nation's focus away from energy efficiency to other issues. As a result, energy use began to rise and energy efficiency improvements slowed. Many opportunities for improving efficiency were not realized. Recent events in the Middle East have renewed concerns about U.S. dependence on foreign energy supplies and stimulated interest in energy efficiency. There are a variety of technologies that have the potential for improving energy efficiency over the next 20 years. New technologies are constantly being added. This chapter describes some of these technologies. (See table 2-1.) But first, the chapter characterizes energy use today, the changes that have occurred since the early 1970s, and what we can expect in the future. Also, this chapter discusses nontechnical factors that influence energy use.

U.S. ENERGY USE

In 1989, the United States used a record-breaking amount of energy. (See table 2-2.) Low oil prices stimulated economic growth (3 percent in 1989) and an increase in energy demand. Petroleum consumption accounted for the lion's share (42 percent) of total U.S. energy use. Natural gas use rose substantially, while coal use registered a slight increase from 1988 to 1989.[1]

Net energy imports also grew, with petroleum accounting for most of the trade. Petroleum net imports reached their highest level since 1979, accounting for 41 percent of U.S. crude oil demand in 1989. Record energy use and a slight decline in domestic production accounted for the increase.[2] The U.S. Department of Energy (DOE) indicates that petroleum net imports for 1990 declined by 2 percent.[3]

All sectors of the economy experienced increased energy use in 1989. In fact, the residential/commercial and transportation sectors used more energy than ever before.[4] (See table 2-3.) While energy use increased, energy intensity[5] declined by 1.7 percent. According to the U.S. Energy Information Agency (EIA), favorable weather conditions contributed to the decline.

Changes in Energy Use From 1972 To 1988[6]

From 1972 to 1988, two trends in energy consumption are discernible. The first trend, from 1972 to 1985, can be characterized by decreasing energy use per dollar of gross domestic product (GDP) and rising energy prices. This was a departure from the 1950s and 1960s when energy use and GDP increased at the same rate. From 1985 to 1988, the trend of steady decreases in energy intensity was broken.

Changes in Energy Use From 1972 To 1985

Between 1972 and 1985, energy use remained essentially flat (0.3 percent per year) while the economy experienced an average growth rate of 2.5 percent per year. This relatively flat level of energy use coupled with economic growth resulted in a drop in energy intensity by 2.4 percent per year or about 25 percent over this period. Fuel use also changed during this period. An almost nearly equal increase in coal and electricity use was offset by a relatively large decrease in crude oil and natural gas consumption.

The implementation of energy efficiency improvements in production processes and structural shifts in the economy toward less energy-intensive

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[1] U.S. Energy Information Administration, Department of Energy, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, p. 1.

[2] Ibid., p. 2.

[3] U.S. Energy Information Administration, *Monthly Energy Review March 1991*, DOE/EIA-0035(91/03), Mar. 28, 1991.

[4] U.S. Energy Information Administration, op. cit., footnote 1.

[5] Energy intensity is defined as the amount of energy used per net unit of economic value (e.g., Btu per dollar of gross domestic product).

[6] Much of the information in this section is drawn from the OTA report, *Energy Use and the U.S. Economy*, OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990).

Table 2-1—Technologies Affecting Demand

Technology	Sector	Availability	Comments
Variable speed heat pump	Residential/commercial	C,N	Improves energy efficiency and provides more flexible control. Widely used in Japan. Increasing market share in United States.
Scroll-type compressors (heat pump/air conditioning)	Residential/commercial	C	Newer scroll-type compressors are 10 to 20 percent more efficient than reciprocating ones. Widely produced in Japan.
Thermally active heat pump	Residential/commercial	R	Could have significant impact in 10 to 20 years.
Low-emissive windows	Residential	C,R	Significant impact on reducing thermal energy loss in homes. Research needed on improving durability, lowering emittance, and reducing condensation.
Heat pump water heaters	Residential/commercial	C	Offers significant reduction in electricity use; premium cost. Commonly used in Scandinavia.
Alternative insulation materials	Residential	R	Needed to counter loss of chlorofluorocarbon-blown insulation. Now being developed and tested.
Refrigerator insulation	Residential	R	Greatest potential for appliance efficiency improvements. New products include vacuum insulation, compact vacuum insulation, and soft vacuum insulation.
Efficient lighting products	Residential/commercial	C,N,R	Combination of lighting options can cut commercial energy use significantly. Improved fluorescents, compact fluorescents, and electronic ballasts commercially available. Research and development continuing on improving phosphors.
Building energy management and control systems	Residential/commercial	C,N	Greatest potential for savings in the commercial sector. Advances in this technology have been continual.
Industrial process changes:			
—Separation	Industrial	C,N,R	Improvements in separation and control, and the use of membrane technology and solvent extraction could reduce energy use considerably.
—Catalytic reaction	Industrial	C,N,R	By increasing reaction rates, lower temperatures and pressures can be used that reduce heating and compression requirements. Discovery and use of new synthetic zeolites have contributed to energy efficiency gain in petroleum refining and chemicals industries.
—Computer control and sensors	Industrial	C,N	Improved monitoring and control optimizes conversion and distribution of energy. Potential savings range from 5 to 20 percent.
Advanced turbine:			
—Steam-injected gas turbine (STIG)	Industrial/utility	C,N	Currently used in cogeneration applications.
—Intercooling (ISTIG)	Industrial/utility	N	Has potential to raise efficiency to about 50 percent. May be better suited for utility applications; pilot-plant stage.
Electric motors	Industrial	C	Adjustable-speed drive and new high-efficiency motors account for about half of the total potential savings in U.S. motors.
2-stroke engine	Transportation	R	Holds promise for long term. Questions remain about ability of engine to comply with emissions standards.
Direct injection/adiabatic diesel	Transportation	C,R	Limited passenger car application in Europe; offers considerable efficiency improvements for both light-duty vehicles and heavy trucks. Questions remain regarding meeting more stringent emission standards.
Ultra-high bypass engines	Transportation	C	Can raise efficiency by about 20 percent but costs two times as much as current generation bypass engines.
Alternative fuels:			
—Alcohol fuels	Transportation	C,N,R	Use of methanol and ethanol should result in greater engine efficiency but costs are higher.
—Electricity	Transportation	R	Big greenhouse advantage if derived from nuclear or solar energy.

KEY: C = commercial; N = nearly commercial; R = research and development needed.

SOURCE: Office of Technology Assessment, 1991.

industries were primarily responsible for lowering energy intensity and changes in fuel use during this period. About two-thirds of the decline in energy intensity can be attributed to energy efficiency improvements. The remaining third came from a shift in the economy caused by changes in consumer demand and by technological improvements in production processes that indirectly saved energy. If energy efficiency improvements had not been implemented during this period, the United States would have required 20 percent more energy in 1985 to produce its output.

Energy consumption per household declined as well. A decrease in use of distillate fuel oil and

Table 2-2—Energy Overview, Selected Years, 1970-89 (quadrillion Btu)

Activity and energy source	1970	1975	1980	1985	1986	1987	1988	1989
Production:								
Crude oil and lease condensate	20.40	17.73	18.25	18.99	18.38	17.67	17.28	16.12
Natural gas plant liquids	2.51	2.37	2.25	2.24	2.15	2.22	2.26	2.16
Natural gas[a]	21.67	19.64	19.91	16.91	16.47	17.05	17.49	17.78
Coal	14.61	14.99	18.60	19.33	19.51	20.14	20.74	21.35
Nuclear electric power	0.24	1.90	2.74	4.15	4.47	4.91	5.66	5.68
Hydroelectric power	2.63	3.15	2.90	2.94	3.02	2.59	2.31	2.77
Other[b]	0.02	0.07	0.11	0.21	0.23	0.24	0.23	0.22
Total production	62.07	59.86	64.76	64.77	64.23	64.82	65.97	66.07
Imports:								
Crude oil[c]	2.81	8.72	11.19	6.81	9.00	10.07	11.03	12.60
Petroleum products[d]	4.66	4.23	3.46	3.80	4.20	4.10	4.72	4.57
Natural gas	0.85	0.98	1.01	0.95	0.75	0.99	1.30	1.39
Other[e]	0.07	0.19	0.31	0.54	0.48	0.60	0.52	0.40
Total imports	8.39	14.11	15.97	12.10	14.43	15.76	17.56	18.95
Exports:								
Coal	1.94	1.76	2.42	2.44	2.25	2.09	2.50	2.64
Crude oil and petroleum products	0.55	0.44	1.16	1.66	1.67	1.63	1.74	1.84
Other[f]	0.18	0.16	0.14	0.14	0.14	0.13	0.17	0.29
Total exports	2.66	2.36	3.72	4.23	4.05	3.85	4.41	4.77
Adjustments[g]	–1.37	–1.07	–1.05	1.31	–0.36	0.12	1.08	1.10
Consumption:								
Petroleum products[h]	29.52	32.73	34.20	30.92	32.20	32.87	34.23	34.20
Natural gas	21.79	19.95	20.39	17.83	16.71	17.74	18.55	19.40
Coal	12.26	12.66	15.42	17.48	17.26	18.01	18.85	18.90
Nuclear power	0.24	1.90	2.74	4.15	4.47	4.91	5.66	5.70
Hydroelectric power[i]	2.65	3.22	3.12	3.36	3.39	3.07	2.64	2.92
Other[j]	–0.04	0.09	0.08	0.20	0.21	0.25	0.27	0.20
Total consumption	66.43	70.55	75.96	73.95	74.24	76.84	80.20	81.35

[a] Dry natural gas.

[b] Includes electricity produced from geothermal, wood, waste, wind, photovoltaic, and solar thermal sources connected to electric utility distribution systems (see note below).

[c] Includes imports of crude oil for the Strategic Petroleum Reserve, which began in 1977.

[d] Includes imports of unfinished oils and natural gas plant liquids.

[e] Includes coal, coal coke, and hydroelectric power.

[f] Includes natural gas, coal coke, and hydroelectric power.

[g] A balancing item. Includes stock changes, losses, gains, miscellaneous blending components, and unaccounted for supply.

[h] Petroleum products supplied includes natural gas plant liquids and crude oil burned as fuel.

[i] Includes industrial generation of hydroelectric power and electricity imports.

[j] Includes electricity produced from geothermal, wood, waste, wind, photovoltaic, and solar thermal sources connected to electric utility distribution systems (see note below) and net imports of coal coke.

NOTE: Data do not include the consumption of wood energy (other than that consumed by the electric utility industry), which amounted to an estimated 2.4 quadrillion Btus in 1987. This table also does not include small quantities of other energy forms for which consistent historical data are not available, such as geothermal, waste, wind, photovoltaic, or solar thermal energy sources except that consumed by electric utilities. Sum of components may not equal total due to independent rounding.

SOURCE: U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89) May 24, 1990; *Monthly Energy Review April 1991*, DOE/EIA-0035 (91/04), Apr. 26, 1991, p. 17.

kerosene accounted for most of the decline.[7] Higher oil prices triggered conservation, efficiency improvements, and fuel switching. The two recessions that occurred during this period also helped to restrain consumption. The OTA report *Energy Use and the U.S. Economy* provides a detailed discussion of shifts in energy use over the last two decades and what is likely to happen in the future.

Changes in Energy Use From 1985 To 1988

Energy use increased by 8 percent, a significant departure from the previous 13-year trend. More than half of the increase was supplied by petroleum. All sectors of the economy contributed to the increase. Although energy use rose, energy intensity continued to drop because of the pace of economic growth (11 percent in 3 years). But the level of

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[7] U.S. Energy Information Administration, op. cit., footnote 1, p. 19.

Table 2-3—Consumption of Energy by Sector,[a] 1970-89 (quadrillion Btu)

Year	Residential and commercial[b]	Industrial[b]	Transportation[b]	Electric utilities	Total
1970	21.71	28.63	16.09	16.27	66.43
1971	22.59	28.57	16.72	17.15	67.89
1972	23.69	29.86	17.71	18.52	71.26
1973	24.14	31.53	18.60	19.85	74.28
1974	23.72	30.69	18.12	20.02	72.54
1975	23.90	28.40	18.25	20.35	70.55
1976	25.02	30.24	19.10	21.57	74.36
1977	25.39	31.06	19.82	22.71	76.29
1978	26.09	31.39	20.61	23.72	78.09
1979	25.81	32.61	20.47	24.13	78.90
1980	25.65	30.61	19.69	24.50	75.96
1981	25.24	29.24	19.51	24.76	73.99
1982	25.63	26.14	19.07	24.27	70.85
1983	25.63	25.75	19.13	24.96	70.52
1984	26.50	27.73	19.87	25.98	74.10
1985	26.73	27.12	20.10	26.48	73.95
1986	26.83	26.64	20.76	26.64	74.24
1987	27.62	27.87	21.36	27.55	76.84
1988	29.00	29.01	22.19	28.63	80.20
1989	29.50	29.46	22.38	29.20	81.35

[a] Data do not include consumption of wood energy (other than that consumed by the electric utility industry) which amounted to an estimated 2.4 quadrillion Btu in 1987. This table does not include small quantities of other energy forms for which consistent historical data are not available, such as geothermal, waste, wind, photovoltaic, or solar thermal energy sources except that consumed by electric utilities.

[b] Includes those fossil fuels consumed directly in the sector, utility electricity sales to the sector, and energy losses in the conversion and transmission of electricity. Conversion and transmission losses are allocated to sectors in proportion to electricity sales to sectors.

NOTE: Sum of components may not equal total due to independent rounding.

SOURCE: U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990; *Monthly Energy Review April 1991*, DOE/EIA-0035 (91/04), April 26, 1991, p. 35.

decline slowed considerably to –0.8 percent per year during this period.

An increase in the level of overall spending and a shift in spending toward more energy-intensive products are two of the factors that contributed to the increase in energy use. For example, Federal Government spending dramatically changed as nondefense purchases fell by 16 percent over the 3-year period, and defense purchases grew by 10 percent. In addition, household spending shifted away from nondurable to durable goods like furniture and electronics. OTA found no evidence that businesses' energy efficiencies declined during this period.

Future Energy Use

Increases in energy use should be less in the future than what was experienced between 1985 and 1988, when the annual gross national product (GNP) growth rate was 2.9 percent. The U.S. Department of Labor's moderate economic growth scenario assumes a 2.3 percent GNP growth rate for 1988-2000. In addition, structural changes that result in less energy use and improvements in energy efficiency are likely to continue in the future.

The impact of technology on future energy use is speculative. A variety of energy-saving technologies are available and have the potential for significant energy efficiency gains. The critical factor is whether there is a willingness to implement these technologies. Implementation or adoption will depend on the costs of the technology and the energy it saves, government policies, and consumer acceptance.

Moreover, business decisions to invest in energy-saving technologies are made in the context of many other competing criteria. Industry makes investment decisions that affect energy efficiency on the basis of a strategic planning process that considers not only energy costs but also a number of other factors. The most important of these factors are perception of product demand and competition; the cost of capital, materials, and labor; and government policy.[8]

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[8] U.S. Congress, Office of Technology Assessment, *Industrial Energy Use*, OTA-E-198 (Washington, DC: U.S. Government Printing Office, June 1983), p. 9.

Energy Use by Sector—An Overview

Residential/Commercial Sector

In 1989, energy use in the residential and commercial sectors accounted for about 36 percent of total U.S. energy use. (See table 2-3.) Space heating and cooling accounted for almost 59 percent of the total energy used in the residential sector in 1987 (the most recent year for which data are available), as shown in table 2-4.[9]

Natural gas is the primary energy source for space heating in the residential sector. Electricity is essentially the only energy source for air conditioning and the major source for appliances, which commonly include refrigerators, TVs, ovens, and clothes washers.

In the commercial sector, a few end-uses account for a major portion of total energy use: space heating, cooling and ventilation, and lighting. Electricity is the predominant energy source in commercial buildings, followed by natural gas. In 1986 (the most recent year for which data are available), electricity accounted for almost half of total commercial sector energy use, followed by natural gas (34 percent) and fuel oil (9 percent).[10]

From 1979 to 1986, energy consumption per household declined considerably. A number of factors were responsible for the 20-percent drop in residential energy intensity: reduced household size, improved shell and equipment efficiencies, and lifestyle changes. In the commercial sector, energy use per square foot declined from 115,000 Btus in 1979 to about 89,000 Btus in 1986. The 23-percent drop in commercial energy intensity was the result of efficiency improvements in new buildings and retrofits to existing ones. Geographical shifts and the changing mix of commercial buildings also contributed to the decrease.[11]

The energy intensity of commercial buildings will probably continue to decrease as new, more efficient technologies are absorbed and new construction practices are implemented, but the level of decline will slow due to the proliferation of electronic equipment, such as personal computers, copiers, and communications equipment. From 1984 to 1989, the number of computer workstations increased from 6.5 to 25.3 million.[12] Modern office equipment now requires as much electricity as is used for lighting. In addition, some modern, more powerful electronic equipment may require more electricity than older models. For example, a laser printer requires 5 to 10 times as much electricity as an old impact printer. And, more powerful desktop computers use almost two times as much electricity as the previous generation.

A number of organizations forecast residential and commercial energy use. A few of these are presented in tables 2-5 and 2-6. Each of the forecasts took into account a number of variables, including energy prices, GNP growth, and building and housing stock expansion. With the exception of the American Gas Association (AGA) forecast, residential electricity demand was projected to rise. The electrification of space and water heating was cited as one of the major reasons for the increase in electricity demand. AGA projected no increases in residential electricity demand from the period 1985 to 2000.[13]

These forecasts for commercial energy use are in general agreement for 2000; however, by 2010 forecasts diverge. The variations are a result of different assumptions, perspectives, and forecasting approaches. For example, the EIA forecast assumes electricity prices decrease at an average rate of 0.7 percent per year, while the AGA assumes electricity prices increase at an average rate of 1.9 percent per year.[14]

A variety of energy-efficient products and systems have been developed and commercialized over the past decade. These and new promising energy efficiency developments are the focus of the section

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[9] U.S. Energy Information Administration, op. cit., footnote 1, p. 43.

[10] Ibid., p. 57.

[11] Ibid., p. 41.

[12] U.S. Department of Commerce, Bureau of the Census, *Statistical Abstract of the United States 1990*, 110th Edition (Washington, DC: U.S. Government Printing Office) 1990, "Computers in the Office," special feature.

[13] Howard S. Geller, American Council for an Energy-Efficient Economy, *Residential Equipment Efficiency: A State-of-the-Art Review*, contractor report prepared for the Office of Technology Assessment, May 1988, pp. 39-40.

[14] Howard S. Geller, American Council for an Energy-Efficient Economy, *Commercial Building Equipment Efficiency: A State-of-the-Art Review*, contractor report prepared for the Office of Technology Assessment, May 1988, p. 3.

Table 2-4—Household Energy Consumption by Application and Fuel Source, 1978, 1980-82, 1984, and 1987

	Consumption (quadrillion Btu)					
Application and fuel source	1978	1980	1981	1982	1984	1987
Space heating:						
Natural gas	4.26	3.32	3.81	3.31	3.51	3.38
Electricity[a]	0.41	0.28	0.30	0.27	0.30	0.28
Distillate fuel oil and kerosene	2.05	1.32	1.13	1.05	1.10	1.05
Liquefied petroleum gases	0.23	0.25	0.22	0.19	0.21	0.22
Total	6.95	5.17	5.45	4.81	5.13	4.94
Air conditioning:[b]						
Electricity[a]	0.31	0.32	0.33	0.30	0.36	0.44
Water heating:						
Natural gas	1.04	1.24	1.10	1.08	1.10	1.10
Electricity[a]	0.29	0.31	0.33	0.33	0.32	0.31
Distillate fuel oil and kerosene	0.14	0.24	0.21	0.09	0.15	0.17
Liquefied petroleum gases	0.06	0.07	0.06	0.06	0.06	0.06
Total	1.53	1.86	1.69	1.56	1.62	1.64
Appliances:						
Natural gas	0.28	0.38	0.49	0.39	0.35	0.34
Electricity[a]	1.46	1.55	1.53	1.52	1.53	1.72
Liquefied petroleum gases	0.03	0.04	0.03	0.04	0.04	0.04
Total	1.77	1.97	2.05	1.95	1.92	2.10
Total[b]	10.56	9.32	9.51	8.62	9.04	9.13
Natural gas[b]	5.58	4.94	5.39	4.77	4.98	4.83
Electricity[a]	2.47	2.46	2.48	2.42	2.48	2.76
Distillate fuel oil and kerosene	2.19	1.55	1.33	1.14	1.26	1.22
Liquefied petroleum gases	0.33	0.36	0.31	0.29	0.31	0.32

[a] Includes electricity generated for distribution from wood, waste, geothermal, wind, photovoltaic, and solar thermal electricity.
[b] Includes a small amount of natural gas used for air conditioning.

NOTE: Sum of components may not equal total due to independent rounding.

SOURCE: U.S. Energy Information Administration, *Annual Energy Review* 1989, DOE/EIA-0384(89) May 24, 1990.

"Opportunities for Energy Efficiency Improvements in the Residential and Commercial Sectors."

Industrial Sector

In 1989, energy use in the industrial sector accounted for about 36 percent of total U.S. energy use.[15] Energy is used for direct heat, steam generation, machinery operation, and feedstocks. Oil is frequently used for the production of direct heat or steam generation. Coal is used more for steam generation. Natural gas is dominant in mining and manufacturing because it burns cleanly and is available. Natural gas has also been used as a feedstock for fertilizers. Electricity is primarily used for motors.

Over the years, the industrial sector has continued to rely on these three fossil fuels and electricity, but their relative contributions have changed. For example, coal accounted for a 26-percent share of industrial energy in 1960 but registered only a 13-percent share in 1989. From 1960 to 1989, petroleum's share ranged from 33 to 41 percent to its present 37-percent share. Natural gas use was very similar to that of petroleum. During the same period, electricity use increased from 7 to 14 percent.[16]

Since 1972, the industrial sector has taken numerous steps to reduce its energy use per unit of output. A number of process changes and the application of new technologies, such as sensors and control systems, heat recovery systems, and continuous steel casting have improved energy efficiency. For example, U.S. industries used less energy in 1985 than in 1963 to produce the same mix and level of products. A discussion of promising energy-efficient technologies follows in the section "Opportunities for Energy Efficiency Improvements in the Industrial Sector."

Transportation Sector

In 1989, the transportation sector accounted for about 27 percent of total energy consumption in the United States. The sector, which is almost totally

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[15] U.S. Energy Information Administration, op. cit., footnote 1, p. 13.
[16] Ibid., p. 21.

Table 2-5—Comparison of Residential Energy Use Forecasts

	Primary energy use (quadrillion Btu)			
Forecast	1985	1990	2000	2010
Lawrence Berkeley Laboratory (1987)[a]	15.5	17.0	18.0	19.9
U.S. Department of Energy (1985)[b]	—	17.8	19.8	21.3
U.S. Energy Information Administration (1987)[c]	15.2	16.9	18.6	—
Data Resources, Inc. (1986)[d]	15.0	16.8	17.9	18.7
Gas Research Institute (1985)[e]	—	16.9	17.8	18.7
American Gas Association (1986)[f]	14.3	13.8	14.8	—
Oak Ridge National Laboratory[g]	16.0	17.2	18.4	20.4
National Energy Strategy[h]	—	18.2	(20.8)	23.3

[a] Computer run provided by Jim McMahon, Lawrence Berkeley Laboratory, Berkeley, CA, November 1987.
[b] Office of Planning, Policy and Analysis, U.S. Department of Energy, "National Energy Policy Plan Projections to the Year 2010," Washington, DC, 1985.
[c] U.S. Energy Information Administration, "Annual Energy Outlook 1987," DOE/EIA-0383(87), Washington. DC, March 1988 (base case).
[d] Data Resources, Inc., "Energy Review," Lexington, MA, summer 1986.
[e] Gas Research Institute, "1987 GRI Baseline Projection of U.S. Energy Supply and Demand to 2010," Chicago, IL, December 1987. (Not including wood and other renewable energy sources.)
[f] American Gas Association, "AGA-TERA Base Case 1986-I," Arlington, VA, January 1986.
[g] Oak Ridge National Laboratory, "Energy Efficiency: How Far Can We Go?" ORNL/TM-11441, January 1990, p.7.
[h] National Energy Strategy, First Edition 1991/1992 (Washington, DC: U.S. Government Printing Office, February 1991), p. C-15. NOTE: Year 2000 NES projection interpolated from 1990 and 2010 figures.

SOURCES: Brookhaven National Laboratory, "Analysis and Technology Transfer Annual Report—1986," Upton, NY, August 1987; and other references cited above.

Table 2-6—Comparison of Commercial Energy Use Forecasts

	Primary energy use (quadrillion Btu)			
Forecast	1985	1990	2000	2010
Lawrence Berkeley Laboratory (1987)[a]	11.6	13.3	15.8	18.5
U.S. Department of Energy (1985)[b]	—	13.3	16.1	18.0
U.S. Energy Information Administration (1987)[c]	11.6	12.8	15.4	—
Data Resources, Inc. (1986)[d]	11.5	12.8	14.6	17.4
Gas Research Institute (1985)[e]	—	12.2	14.0	16.7
American Gas Association (1986)[f]	12.7	13.3	15.6	—
Oak Ridge National Laboratory[g]	10.8	13.1	16.0	18.8
National Energy Strategy[h]	—	13.8	(17.6)	21.3

[a] Pacific Northwest Laboratory Commercial Energy Use Model.
[b] Office of Planning, Policy and Analysis, U.S. Department of Energy, "National Energy Policy Plan Projections to the Year 2010," Washington, DC, 1985.
[c] U.S. Energy Information Administration, "Annual Energy Outlook 1987," DOE/EIA-0383(87), Washington, DC, March 1988 (base case).
[d] Data Resources, Inc., "Energy Review," Lexington, MA, summer 1986.
[e] Gas Research Institute, "1987 GRI Baseline Projection of U.S. Energy Supply and Demand to 2010," Chicago, IL, December 1987. (Not including renewable energy sources.)
[f] American Gas Association, "AGA-TERA Base Case 1986-I," Arlington, VA, January 1986.
[g] Oak Ridge National Laboratory, "Energy Efficiency: How Far Can We Go?" ORNL/TM-11441, January 1990, p.7.
[h] National Energy Strategy, First Edition 1991/1992 (Washington, DC: U.S. Government Printing Office, February 1991), p. C-15.

NOTE: Year 2000 NES projection interpolated from 1990 and 2010 figures.

SOURCES: Brookhaven National Laboratory, "Analysis and Technology Transfer Annual Report–1986," Upton, NY, August 1987; and other references cited above.

dependent on petroleum, used 10.85 million barrels per day in 1989, which is more than the United States produces domestically. Its share of total U.S. petroleum consumption was almost 63 percent.[17] The total U.S. automobile fleet alone accounts for about 30 percent of all U.S. oil consumption; the total light-duty fleet, which also includes vans and light trucks, accounts for about 39 percent. The automobile and light-duty fleets are the largest available targets for reducing U.S. oil use.

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[17] Ibid., p. 137.

Over the last two decades, tremendous strides in automobile fuel efficiency have been made. The fuel efficiency of the new car fleet has essentially doubled between 1974 and today. The potential for further reducing energy use in the transportation sector is promising if the industry is given enough lead time. A number of new energy-saving technologies are either on the market or under investigation. They offer the potential to significantly improve fleet fuel economy in the long term (by 2010). In addition, recent interest in developing alternative transportation fuels can have positive effects on energy demand by diversifying fuel supplies and/or reducing demand for gasoline. In the short term, however, a number of factors are expected to slow down the rate of efficiency improvement. These include increasing sales of new high performance and luxury cars, growth in the use of light trucks for passenger travel, and a continued demand for certain older car models. A discussion of promising technologies and alternative fuels follows in the section "Opportunities for Energy Efficiency Improvements in the Transportation Sector."

OPPORTUNITIES FOR ENERGY EFFICIENCY IMPROVEMENTS IN THE RESIDENTIAL AND COMMERCIAL SECTORS

From 1974 to 1986, technical advances in energy-using equipment and building construction practices and materials have significantly improved energy efficiency in the residential and commercial sectors. High energy prices during this period were the impetus for the rapid development and implementation of a variety of energy-saving technologies. Strong government support for research and development (R&D) programs in energy efficiency also contributed to accelerating technology development. However, considerable potential for energy savings remains. In recent years lower energy prices have slowed the rate of efficiency improvement and dampened the prospects for near-term commercialization of new technologies. In addition, Federal funding for energy technology R&D has declined over the last decade. Increasing Federal R&D support could accelerate the development and deployment of energy saving technologies. The following section discusses opportunities for improving energy efficiency in the residential and commercial sectors.

Opportunities for Improving Space Heating and Cooling Efficiency

Space heating and cooling are the most energy-consuming applications in households and commercial buildings. Space heating alone accounts for about two-thirds of total residential sector energy use.[18]

In homes and commercial buildings that use fuels for space heating, newer more energy efficient furnaces and boilers are already common. The Gas Appliance Manufacturers Association (GAMA) estimates that about 47 percent of all new gas furnaces sold have efficiency ratings of between 65 and 71 percent. Gas furnaces with efficiency ratings of 80 percent make up about 33 percent of the market, and 90-percent efficient furnaces make up about 20 percent of the market.[19] Since the early 1980s, these highly efficient furnaces have been promoted by manufacturers and relatively well-received by consumers.

The decision to purchase a super efficient furnace must weigh the increase in initial cost against the increased savings. An Illinois Department of Energy and Natural Resources survey indicates that natural gas furnaces in the 90+-percent efficiency range cost on average about $2,100 to $2,600. An 80-percent efficient furnace can be installed for an average of about $1,500. A comparison of annual savings and paybacks from furnace replacements is shown in figure 2-1.[20]

The best modern furnaces are already close to maximum efficiency (within 10 percent of maximum theoretical efficiency). Improvements in energy efficiency in the sector will depend less on new technology than on encouraging people to use the best available equipment.

In addition, older furnaces can be retrofitted to achieve higher efficiencies by adding such features

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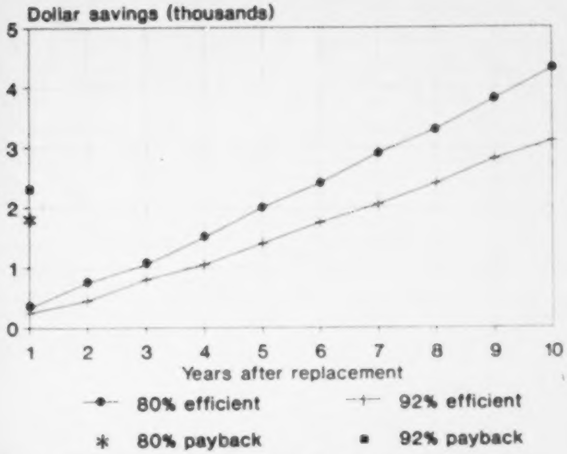
[18] Ibid., p. 43.

[19] Henry C. Kurth and Nicolas P. Hall, "Furnace Replacement: The High Efficiency Payoff," *Home Energy*, vol. 7, No. 3, May/June 1990, p. 22.

[20] Ibid.

Figure 2-1—Furnace Replacement Accumulated Savings (60 percent efficient v. 80 and 92 percent)



With 5-percent escalation included, 92 percent efficient furnaces take 2 years more to pay for themselves than the 80 percent efficient furnaces.

SOURCE: "Furnace Replacement: The High Cost Efficiency Payoff," *Home Energy*, vol. 7, No. 3, May/June 1990.

as flame-retention burners, electric ignition, power burners, and condensing heat extractors. Flame retention burners are a cost-effective measure for oil furnaces. Double-digit energy savings with paybacks of 2 to 5 years are typical for this retrofit. However, other retrofit programs have had mixed success, indicating that investments have to be chosen carefully.[21]

In homes and commercial buildings that use electricity to space heat, heat pumps offer a major opportunity for improving energy efficiency. Heat pumps typically consume one-third to one-half as much electricity for heating as do electric resistance-based systems. However, heat pumps operate at cooler temperatures than furnaces, so the air from the vents may feel drafty and heat the house more slowly. In 1987, heat pumps were used in about 25 percent of all electrically heated housing units. The number of commercial buildings with heat pumps nearly doubled between 1983 and 1986.[22]

Current heat pump technologies do not operate near their maximum theoretical efficiency. Thus, the opportunities for improvement are significant. For example, the development of variable speed controls for capacity modulation will improve efficiency and provide a better match between output and space conditioning needs. One estimate notes that variable speed heat pumps will use 25 to 50 percent less electricity than typical heat pumps installed in the mid-1980s.[23] Incorporating variable speed controls also provides quieter operation, more flexible control, better dehumidification capability, and the possibility of self-diagnostic features.

Variable-speed heat pumps have been available in Japan since the early 1980s. About one-half of all heat pumps in Japan use variable-speed control.[24] Variable-speed heat pumps are also available in the United States. The number of manufacturers offering this technology is growing; and newer, more efficient models are continually being tested and marketed.

Improvements in compressors for heat pumps and air conditioners also promise to have higher efficiency rates than conventional types. For example, newer scroll-type compressors have efficiencies of 10 to 20 percent higher than reciprocating compressors. In addition, scroll-type compressors are smaller, lighter, and quieter. They are widely produced in Japan and are expected to be produced and used in the United States in the near future.

The next major advance in heating/cooling technology may be the thermally active heat pumps (TAHP). A TAHP is similar to a conventional electric heat pump except that the electric motor is replaced by "something" that burns fuel, e.g., an internal combustion engine. Two of the advantages of TAHPs are that they can use a variety of fuels, and they are more efficient than a comparable electric system. TAHPs use exhaust heat from the engine to supplement the heating cycle.[25] TAHPs could have a significant impact on residential and commercial energy use in the next 10 to 20 years, but they will have to be competitive with conventional systems in terms of first cost and maintenance.

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[21] Sam Cohen, "Fifty Million Retrofits Later," *Home Energy*, vol. 7, No. 3, May/June 1990, pp. 14-15.

[22] U.S. Energy Information Administration, *Housing Characteristics 1987*, DOE/EIA-0314(87), May 1989, p. 12; and *Characteristics of Commercial Buildings 1986*, DOE/EIA-0246(86), September 1988, p. 21.

[23] Geller, *Residential Equipment Efficiency*, op. cit., footnote 13, p. 20.

[24] Debbie Lowe, "A New Generation of Heat Pumps," *Home Energy*, vol. 6, No. 2, March/April 1989, p. 12.

[25] Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference?* vol. 2, Part 1, "End-Use Technology," ORNL-654411 V2/P1, December 1989, pp. 33-34.

Both DOE and the Gas Research Institute (GRI) have funded research on TAHPs. A number of advanced TAHPs have been developed. These include internal combustion engine-driven units, free-piston Stirling engine systems, and absorption systems. In the United States, the internal combustion engine-driven units are in the prototype stage and have been tested in the laboratory. The Japanese are also doing research in this area and have manufactured and field-tested a number of internal combustion-driven systems. The best performances are comparable to the best electric systems in cooling, about 75 percent better in heating, and very competitive in operating costs.[26]

Several Stirling engine-driven heat pumps have been developed and tested. Stirling engines are attractive as heat pump drivers because they have the potential to be highly efficient, quiet, and long lasting. The performance of Stirling engine-driven heat pumps has been similar to that of the internal combustion engine.[27]

Similar progress has been made in advanced absorption systems. A number of advanced absorption systems are under development and have been tested in the laboratory. They are about 20-percent more efficient in cooling than the best absorption chillers[28] available.[29] Cost studies have shown that the installed cost for a small absorption heat pump is in the range of installed costs for a gas furnace plus an electric air conditioner.[30]

Other refrigeration equipment efficiency improvements are being developed. These include the use of capacity modulating systems and novel refrigeration cycles. These advancements could improve energy efficiency by 30 to 50 percent.[31]

Opportunities for Improving Building Envelope Efficiency

Efforts are being directed at improving the thermal efficiency of building envelopes. Much of the research has focused on materials that have higher thermal resistance per unit thickness and new envelope configurations that are more thermally resistant.

For wall systems, alternative construction practices have promising potential for improving efficiency. These include innovative designs that keep the structural elements away from the exterior shell and retrofit insulation practices that shield existing thermal bridges (highly conductive heat flow paths). Thermal bridges can reduce the overall thermal efficiency of some wall systems by 30 percent. Demonstration homes in Minnesota that use new insulation techniques use 68-percent less heat than the average U.S. home.[32]

Prospects for new high-thermal-resistant products for wall systems are being explored. These include evacuated or foam cores molded to conform to the exterior shape of the building and molded fiber walls.[33]

Improving the thermal resistance of roofs is somewhat difficult because roofing materials are compact and not much can be done to improve thermal resistance per unit thickness except to focus on materials. Alternatives to chlorofluorocarbon foam insulation are being developed and tested. In addition, waterproof membranes must be developed that can maintain their resiliency through continual thermal stressing over periods of 20 years or more. And, improved techniques must be developed for fastening roof elements to the structural building.[34]

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[26] Ibid., p. 34.

[27] Ibid., p. 35.

[28] Absorption chillers are the only available fuel-burning refrigeration systems. They can burn either natural gas or oil to produce chilled water for cooling. Absorption chillers are not widely used in the United States because they are not cost and/or performance competitive with current electric systems. But in Japan, where energy costs are higher and the Government favors systems that use natural gas, 80 percent of all commercial buildings are cooled with absorption chillers.

[29] Oak Ridge National Laboratory, op. cit., foonote 25, p. 35.

[30] Geller, *Residential Equipment Efficiency*, op. cit., footnote 13, p. 23.

[31] Oak Ridge National Laboratory, op. cit., footnote 25, p. 33.

[32] J.H. Gibbons, P.D. Blair, and H.S. Gwin, "Strategies for Energy Use," *Scientific American*, vol. 262, No. 3, September 1989, p. 141.

[33] Oak Ridge National Laboratory, op. cit., footnote 25, pp. 25, 39.

[34] Ibid., p. 39.

A number of successful innovations have improved the thermal efficiency of windows. As much as 25 percent of residential and 4 percent of U.S. total energy use escapes through windows.[35] Thus, the potential for reducing energy use is significant.

The introduction of two coatings technologies has improved window performance substantially. One technology applies a heat reflective coating directly on the glass, and the other applies similar coatings to a clear polyester film that is mounted inside sealed insulating glass. Low-emittance (low-e) coatings and films have increased glass insulation values up to as much as R-4.5. For example, the addition of low-e coatings to a double-pane glass increases the insulation value of a window up to as much as R-3. (A single-pane glass is roughly the equivalent of R-1; double-pane, R-2; and triple-pane, R-3.) To increase further the insulation value, a colorless inert gas, such as argon, can be added inside a sealed low-e window unit, thereby increasing the R value to R-4. Using a heat reflective coating on a clear, colorless film mounted inside a double-pane window unit can increase the R value to R-4.5.[36]

In January 1990, a window with an R-8.1 insulating value was introduced. The use of multiple-coated films mounted inside sealed insulated glass made this development possible. This window achieves almost the thermal resistance of an ordinary insulated stud wall, thus greatly reducing a major heat leakage. In addition, it reduces sound transmission much more effectively than ordinary windows (important near highways and airports) and virtually eliminates ultraviolet light, which damages fabrics. However, it is significantly more expensive. Hurd Wood Windows quotes prices for a typical 2′6″ x 5′ casement window as: $257 for R-2.6 clear, double-glazed; $320 for R-4.1 with a single coated film; $441 for R-8.1 double film (quadruple glaze) with inert gas. In a moderate climate, the R-8.1 window would save less than 10 dollars' worth of energy per year relative to the R-2.6 window which is not a good return for investment of $184. Thus these windows are economical only in severe climates or where the other features are valued.

Two of the most important advantages of improving window insulation performance are: 1) reducing energy costs and 2) increasing the capacity of existing heating, ventilation, and air conditioning (HVAC) systems or allowing the use of smaller HVAC systems in new construction and renovations.[37] Many new window products that incorporate these innovations are already on the market. In fact, a few large window manufacturers have standardized lowe glass products. And, DOE indicates that demand for low-e windows has increased 5 percent annually since the products were introduced in 1983.[38] Additional research is being conducted on improving the durability of the coatings and lowering their emittance and reducing condensation.

Opportunities for Improving Water Heating Efficiency

Incremental efficiency improvements have been achieved by adding insulation wraps or installing convection-inhibiting heat traps to existing water heaters. Also, more efficient conventional water heaters are commercially available at a modest increase in first cost of about $20 to $100. These more efficient water heaters provide 10- to 25-percent energy savings with a $1^{1}/_{2}$- to 3-year payback.

Innovative water heaters were developed and commercialized in the 1980s. Heat-pump water heaters, for example, use about 50-percent less electricity than conventional electric water heaters. A heat-pump water heater can cost anywhere from $800 to $1,200, four times that of a conventional electric water heater.[39]

Heat-pump water heaters can be operated together with a mechanical ventilation system in houses that have low infiltration. The heat pump removes heat from the exhaust air stream during the heating season and from the incoming air stream during the cooling season and uses this heat to operate the water heater. The ventilation air streams are a very efficient source of heat for the heat-pump water heater. Such systems are commonly used in Scandinavia.[40]

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[35] Rick Bevington and Arthur H. Rosenfeld, "Energy for Buildings and Homes," *Scientific American*, vol. 263, No. 3, September 1990, p. 80.

[36] Todd W. Sitrin, "Windows for the '90s," *Public Power*, May-June 1990, vol. 48, No. 3, pp. 40-41.

[37] Ibid., p. 41.

[38] "Window Company Standardizes Low-E Glass," *Home Energy*, vol. 7, No. 3, May/June 1990, p. 6.

[39] E. Hirst, J. Clinton, H. Geller, and W. Kroner, American Council for an Energy-Efficient Economy, *Energy Efficiency in Buildings: Progress and Promise* (Washington, DC: 1986).

Highly efficient gas- or oil-fired water heating is possible by coupling a hot water tank to a high-efficiency space heating furnace. This achieves water heating efficiencies of 80 to 85 percent and saves fuel. A similar technology recently introduced is a high-efficiency integrated space and water heating system. It features electric ignition, a power burner, and flue gas condenser to provide both space and water heating at efficiency levels of 85 to 90 percent. Neither the heat-pump water heater nor the high-efficiency integrated gas-fired space and water heating system has significantly penetrated the marketplace. Low sales are attributed to high first cost and limited availability.[41]

GRI has supported the development of a gas water heater with pulse combustion and flue gas condensation (similar to the most efficient gas furnaces). It is estimated that the water heater will use 25 to 40 percent less fuel than conventional gas heaters currently produced. The estimated retail cost is about $900, roughly three times that for a standard water heater.[42]

Opportunities for Improving Lighting Efficiency

Lighting is the second largest end-use in the commercial sector and a significant portion of total energy use. Fluorescent lights are heavily used in commercial buildings.

Fluorescent lamps are being improved through size and weight reductions. For example, switching from standard fluorescent ballasts to electronic ballasts that weigh only about four ounces can decrease energy use. Lawrence Berkeley National Laboratory developed a high-frequency, solid-state ballast that increases lamp efficiency by 20 to 25 percent.[43] Adding an optical reflector to fluorescent lamps increases useful light output by 75 to 100 percent, cutting energy use by 30 to 50 percent.[44]

Photo credit: Chris Calwell, courtesy of Home Energy *Magazine*

The availability of energy-efficient lighting products has increased significantly in recent years.

Another option for improving fluorescent lighting efficiency is to develop more efficient phosphors. Phosphors currently in use are 40-percent efficient. Research is underway to develop phosphors that convert one ultraviolet photon into two visible photons, resulting in 75-percent efficiency and reducing energy use by 50 percent.[45]

In the commercial sector, a combination of options, such as replacing standard fluorescent lamps and ballasts with energy efficient types; replacing incandescent bulbs with fluorescent lighting; and installing reflectors, lighting controls, and occupancy sensors could cut electricity use for lighting by nearly 50 percent. Overall electricity use in the commercial sector could drop by about 20 percent.[46] Of course, the decision to retrofit must weigh the initial costs against the increased savings.

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[40] Geller, *Residential Equipment Efficiency*, op. cit., footnote 13, pp. 6, 19.

[41] Ibid., p. 7.

[42] Ibid., pp. 19-20.

[43] Oak Ridge National Laboratory, op. cit., footnote 25, p. 36.

[44] Geller, *Commercial Building Equipment Efficiency*, op. cit, footnote 14, p. 12.

[45] Oak Ridge National Laboratory, op. cit., footnote 25, p. 36.

[46] M.J. Wallin, S. Balakrishnan, and C. McDonald, "Commercial/Governmental Electricity Conservation Potential," report prepared by Synergic Resources Corp. for the Public Service Commission of the District of Columbia, Washington, DC, March 1987.

The costs of retrofitting conventional lighting fixtures to more efficient ones are very site-specific. A recent lighting retrofit project conducted by the U.S. Postal Service showed a cost of $81 per lighting fixture. The retrofit included the installation of reflectors, magnetic ballasts, and new lamps.[47]

In the residential sector, energy use for lighting accounts for only about 7 percent of the total sector energy use.[48] Almost all residential lighting is provided by incandescent lamps. One way incandescent bulbs can be improved is by placing a quartz tube around the filament. The quartz tube has an optical coating that passes visible light but reflects infrared radiation. General Electric has introduced a 350-watt quartzline lamp that replaces a standard 500-watt lamp, and it is expected that this development will eventually reach households.[49]

In the early 1980s, compact fluorescent lamps were introduced to replace incandescent bulbs. Fluorescent lamps provide 3 to 5 times more light per watt of power consumed and last 5 to 10 times longer. But, they cost between $10 and $20 each. Consequently, they have been marketed primarily to the commercial and industrial sectors where lights are used more extensively. The installation of compact fluorescent light bulbs in Newark, New Jersey schools, for example, cut electricity use by 15 to 20 percent, reduced maintenance, and increased illumination levels.[50]

Because compact fluorescent lamps are larger than incandescent types, have color rendering problems, cost the consumer more, and are often difficult to find, residential market penetration is low. However, if the most heavily used incandescent bulbs were replaced with compact fluorescents, total electricity use for household lighting could drop by 30 to 40 percent.[51] Thus, the potential for energy savings is significant.

Opportunities for Improving Appliance Efficiency

Refrigerators and Freezers

In recent years, the energy efficiency of refrigerators and freezers has improved considerably. However, there is still significant potential for improvements. About two-thirds of refrigerator/freezer energy use is due to heat transfer through walls and not from door openings and food cooling.[52]

New advances in insulation products are under development. These technologies take advantage of the heat-transfer properties of a partial vacuum or trapped layers of gas to achieve higher insulation values. One type of vacuum insulation being examined uses rigid steel barriers, glass spacers, and a very low pressure or hard vacuum. Others use low-density fillers and a higher-pressure soft vacuum. Yet another concept uses no vacuum but traps gas within a number of reflective barriers.[53]

For soft vacuum insulation designs, silicon-based gels and fine powders are being tested. Aerogel insulation panels have been installed in standard refrigerators for testing by DOE. Thermalux, a California firm that manufactures aerogel panels, estimates that they would cost appliance manufacturers between $1 and $2 per square foot.[54]

Materials that have been examined for powder insulation fillers are fumed silica, precipitated silica, silica dust, perlite, glass fiber, glass wool, and fly ash. Costs for these materials vary. For example, fumed silica is expensive but performance is high. Precipitated silica, fly ash, and perlite also work well and are cheaper.[55]

The use of these new vacuum insulation designs in refrigerator/freezers could reduce their electricity consumption by 25 to 50 percent. Japanese manufacturers already incorporate first-generation, soft vacuum panels into some of their models. These panels have measured insulating values of R-16 to R-20 per inch of thickness. However, some concerns about panel insulation durability and maintenance have been raised. These concerns will have to be addressed before these products are used extensively in the United States.[56]

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[47] Martin Nelson, Division Energy Coordinator, U.S. Postal Service, personal communication, San Diego, CA, Sept. 26, 1990.

[48] U.S. Energy Information Administration, Department of Energy, *Energy Conservation Multi-Year Plan, FY1989-93*, 1987.

[49] Geller, *Residential Equipment Efficiency*, op. cit., footnote 13, p. 24.

[50] Bevington and Rosenfeld, op. cit., footnote 35, p. 78.

[51] Ibid., p. 11.

[52] David J. Houghton, "Refrigerator Insulations for the 21st Century," *Public Power*, November/December 1990, p. 48.

[53] Ibid., p. 49.

[54] Ibid.

[55] Ibid.

The Solar Energy Research Institute (SERI) and the Lawrence Berkeley Laboratory (LBL) have pursued different approaches to vacuum insulation. SERI has built a number of prototype panels that incorporate steel outer layers and glass spacers. The prototype panels, called compact vacuum insulation (CVI), are estimated to cost refrigerator/freezer manufacturers between $1 and $4 per square foot. Because the panel is very thin, the interior volume of a refrigerator/freezer could be increased. Appliance industry estimates indicate that additional volume could be worth $45 to $50 per cubic foot, and could help offset the high cost of the insulation. Thus far, manufacturers have shown little interest in CVI.[57]

LBL has been developing superinsulated gas-filled panels that resemble windows more than refrigerator/freezer insulation panels. The estimated cost to the appliance manufacturer is $0.40 to $1.50 per board foot. The panels use a number of sheets of low-e plastic separated by air gaps, which are loosely filled with very thin, crumpled low-e plastic material. The entire panel is filled with low conductivity gas and sealed. LBL has applied for a patent.[58]

Another promising option is to shift from one to two refrigeration systems. This improves thermodynamic efficiency and results in less dehydration of food in the refrigerator compartment. Refrigerator-freezers with dual refrigeration systems are manufactured in Europe.[59]

The use of electronic variable speed controls is another way to improve the efficiency of refrigeration systems. Electronic variable speed controls, which modulate cooling output, can produce electricity savings of about 20 percent.[60]

Cooking and Laundry

There have been a number of promising developments in cooking technology and clothes drying. For example, a high-efficiency electric oven, called the biradiant oven, was developed and demonstrated in the 1970s. Its features include highly reflective walls and two heating elements that operate at relatively low temperatures. Tests show that the biradiant oven uses about 60-percent less electricity than conventional ovens. Manufacturers have shown little interest in producing the biradiant oven even though it appears to be technically and economically viable.[61]

Another development, the infrared-jet impingement burner for gas stove tops, promises fuel savings of 15 to 25 percent. This burner utilizes a high degree of radiative heat transfer from a ceramic flame holder. Other advantages of the infrared jet impingement burner are a reduction in nitrogen oxide and carbon monoxide emissions, uniform heating, fast response, and ease of cleaning. GRI field-tested the burner and is continuing to reduce production cost and increase lifetime.[62]

Some promising advances in clothes dryers are on the horizon. A heat-pump clothes dryer has been developed, and tests show electricity savings of 50 to 60 percent relative to a conventional clothes dryer. (Larger-scale heat pump dryers are used for drying lumber and food products.) The heat-pump clothes dryer has a drain pipe rather than an exhaust vent, which is advantageous in apartment buildings. A major disadvantage is its cost. The estimated retail price of the dryer is $600 to $700, about twice that of a conventional electric dryer. The payback on the extra first cost is about 8 years. Commercialization and marketing are expected to begin in the near future.[63]

Microwave clothes dryers are also under development. However, there are problems with high water retention when drying larger loads.

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[56] Geller, *Residential Equipment Efficiency*, op. cit., footnote 13, p. 18.

[57] Houghton, op. cit., footnote 52, p. 50.

[58] Ibid.

[59] Geller, *Residential Equipment Efficiency*, op. cit., footnote 13, p. 17.

[60] Ibid.

[61] Ibid., p. 24.

[62] Ibid., pp. 24-25.

[63] Ibid., p. 26.

Opportunities for Improving Energy Management and Control Systems

Energy management and control systems are used to monitor and adjust heating and air conditioning, lighting, and other energy-using appliances, primarily in commercial buildings. Energy management and control systems are diverse and vary from a simple thermostatic control to complex pneumatic control systems with many sensors, microprocessors, and other components.

Behavioral changes, particularly changes in indoor air temperatures, are an important element in building energy management programs. The EIA, which has been tracking indoor air temperatures since 1981, reports that winter indoor air temperatures dropped during the 1973-84 period. This drop was an important factor in the decline in U.S. residential energy use during this time.[64]

Improvements in control technologies and sensors, and diagnostic equipment could result in energy savings as high as 10 to 15 percent of total U.S. energy use. The commercial sector offers the greatest potential for savings.[65]

Strides have also been made in the residential sector. Automated control systems comparable to those used in commercial buildings are now being installed in houses. These "smart" houses, as they are commonly called, are being promoted by a number of manufacturers, utilities, the Electric Power Research Institute, and the National Association of Home Builders. For example, the Southern California Edison Co. and a number of local builders initiated a House of the Future pilot project. New homes are equipped with automated systems and controls and a number of energy-saving technologies, such as compact fluorescent light bulbs, energy efficient appliances, and occupancy sensors.[66]

Over the years, advances in energy management and control have been continual. Nevertheless, some opportunities still have not been realized. For example, there is a lack of reliable, low-cost meters for measuring oil and natural gas use in buildings. Also, humidity sensors need further development.[67]

OPPORTUNITIES FOR ENERGY EFFICIENCY IMPROVEMENTS IN THE INDUSTRIAL SECTOR[68]

The industrial sector is both diverse and large. It uses energy for probably a wider variety of purposes than does any other sector of the economy. Energy is used for direct heat, steam generation, machinery operation, and feedstocks. The most intensive industrial processes involve the direct application of heat to break and rearrange molecular bonds through chemical reactions. Processes such as smelting, cement manufacture, and petroleum refining typically involve large amounts of heat.

Since it peaked in 1970, industrial energy use per unit of output (energy intensity) has been declining due to a number of factors: efficiency improvements, innovative process changes and the application of new technologies, changes in the product mix (level and demand for products), and the price of energy. Many of the energy efficiency gains realized over the last decade have been the result of good business practices.

Most firms regard energy efficiency in the context of a larger strategic planning process. Investments are evaluated and ranked according to a variety of factors: product demand, competition, cost of capital, labor, and energy. Thus, energy-related projects are not treated differently from other potential investments and must contribute to the corporate goals of increased profitability and enhanced competitive position. This view has important policy implications for reducing energy demand. Incentives aimed at decreasing energy demand growth must compete with other strategic factors and therefore have to be substantial to make a significant impact.

OTA found that the best way to improve energy efficiency in the industrial sector is to promote general corporate investment. Lowering interest rates would increase capital availability and allow more projects to be undertaken. Industries that believe energy prices will continue to rise have a strong impetus to use capital for more energy efficient equipment. However, it should be noted that growth in product demand is essential if investment is to take place, even with lower interest rates. The OTA report *Industrial Energy Use* provides a more indepth discussion of corporations' investment behavior.

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[64] Steven Meyers, "Energy Consumption and Structure of the U.S. Residential Sector: Changes Between 1970 and 1985," *Annual Review of Energy 1987*, vol. 12, 1987, pp. 92-93.

[65] Oak Ridge National Laboratory, op. cit., footnote 25, p. 28.

[66] Bevington and Rosenfeld, op. cit., footnote 35, p. 82.

[67] Oak Ridge National Laboratory, op. cit., footnote 25, p. 28.

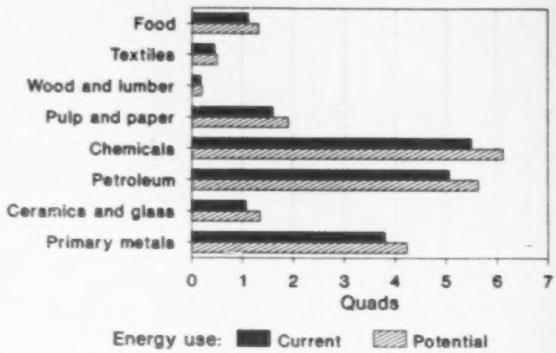
[68] For a more indepth discussion of industrial energy use, see OTA report *Industrial Energy Use*, op. cit., footnote 8.

While the industrial sector has made impressive strides in reducing energy use, opportunities for further gains in energy efficiency have by no means been exhausted. A number of promising developments in crosscutting technologies are discussed below. They include computer control systems and sensors, waste heat recovery, cogeneration, catalysts, separation processes, combustion, and electric motors. Also, opportunities for improving energy efficiency in four of the most energy-intensive industries—pulp and paper, petroleum refining, chemicals, and steel industries—follows.

Computer Control and Sensors

Computer control systems and sensors are added to existing equipment, such as a boiler, to improve the performance, or to an industrial process to monitor the production line for wastage and quality control. In a production line, computerized process control systems can be used to optimize such things as paper thickness, polymer color, or petroleum viscosity. Almost any energy-using process can be made more efficient if specific parameters at each point in the process can be measured and conditions optimized. Figure 2-2 shows the potential for energy savings associated with improved sensor technology for several industries. Potential savings in the range of 5 to 20 percent can be achieved for each of the industries. In addition, improved sensors have the potential for reducing total industrial energy use by 10 percent.[69]

Figure 2-2—Potential Energy Savings With Improved Sensor Technology



SOURCE: U.S. Department of Energy, the DOE Industrial Energy Conservation Program, Research and Development in Sensor Technology, DOE/NBM-7012450, April 1987, p. 4.

Waste Heat Recovery

Whenever fuel is burned, the products of combustion are a potential source of waste heat. Therefore the recovery of waste heat has enormous potential for saving energy. Waste heat recovery systems can improve the overall energy efficiency by recovering heat from combustion gases in a steam boiler or from excess thermal energy from a process stream product. A great deal of waste heat recovery has been taking place, especially since 1974.

Traditional approaches to heat recovery include transferring heat from a high-temperature, waste heat source (combustion gases) to a more useful medium, e.g., steam, for low-temperature use; or upgrading thermal energy to a level that can be useful as a heat source. Heat exchangers are used for the former approach and vapor recompression and heat pumps are used for the latter.

New approaches to waste heat recovery have been broadened to include improved monitoring and control to optimize conversion and distribution of energy. A 1985 survey indicated that waste heat recovery could reduce energy inputs by 5 percent in petroleum refineries. In the chemicals industries, existing waste heat recovery programs have reduced energy usage per pound of product by 43 percent since 1974.[70]

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[69] Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference*? vol. 2, Part 3, "Cross-Cutting Science and Technology," ORNL-6541/V2/P3, December 1989, p. 11.

[70] Oak Ridge National Laboratory, op. cit., footnote 25, pp. 71, 76.

[71] A more detailed discussion of cogeneration and its potential impacts can be found in *Industrial and Commercial Cogeneration* U.S. Congress, Office of Technology Assessment, OTA-E-192 (Washington, DC: U.S. Government Printing Office, February 1983).

Cogeneration[71]

Cogeneration is defined as the production of both electrical or mechanical power and thermal energy from a single energy source. In industrial cogeneration systems, fuel is first burned to produce steam. The steam is then used to produce mechanical energy at the turbine shaft, where it can be used directly, but more often is used to turn the shaft of a generator, thereby producing electricity. The steam that leaves the turbine still has sufficient thermal energy to provide heating and mechanical drive throughout a plant.

The principal technical advantage of a cogeneration system is its ability to improve fuel efficiency. A cogeneration facility uses more fuel to produce both electric and thermal energy. However, the total fuel used to produce both energy types is less than the total fuel required to produce the same amount of power and heat in separate systems. A cogenerator will achieve overall fuel efficiencies 10 to 30 percent higher than separate conventional energy conversion systems.

Major industrial cogenerators are the pulp and paper, chemicals, steel, and petroleum refining industries. The pulp and paper industry has been a leader in cogeneration because it has large amounts of burnable wastes (bark, scraps, forest residues unsuitable for pulp) that can supply energy needed for plant requirements. The industry considers power production an integral part of the manufacturing process.

In the 1980s, a favorable economic and regulatory climate encouraged the growth of cogeneration in the industrial sector. Since the passage of the Public Utility Regulatory Policies Act (PURPA) in 1978, the amount of electricity received by utilities from nonutility sources has grown dramatically. According to the Edison Electric Institute, electricity sales to utilities from nonutility sources increased from 6,034 gigawatt-hours (GWh) in 1979 to 93,677 GWh in 1989. The latter figure represents 3 percent of the total electricity available to the utility industry for distribution.[72]

Estimates of current and projected nonutility capacity vary considerably, however, so it is difficult to measure the growth of this industry with precision. Although there is no definite count of nonutility capacity in the United States, the Edison Electric Institute estimated that 40,267 megawatts (MW) of nonutility capacity was in operation at the end of 1989. Cogeneration accounted for 29,216 MW, or about 73 percent of the total.[73]

Estimates of future capacity growth also vary. Several estimates suggest that roughly 38,000 MW of capacity will be online by 1995. By the year 2000, other studies estimate that nonutility capacity will be as high as 80,000 MW.[74]

In the 1980s, a favorable economic and regulatory climate encouraged the growth of cogeneration in the industrial sector.

Advanced turbines have attracted renewed attention for cogeneration applications because they can save energy and provide fuel flexibility. Over time, turbine efficiency and size have increased considerably as new turbine technologies and advanced materials allowed for hotter combustion temperatures.[75] Many of the advances in design and high temperature materials for turbines result from military R&D for improved jet engines.

In addition to hotter combustion temperatures, capturing the energy of the hot exhaust gases to make useful steam offers further options to improve efficiency. A process receiving increased attention is the steam-injected gas turbine (STIG). In the STIG, steam is injected into the turbine's combustor. The result is greater power and electrical efficiency. For example, in turbine units based on General Electric's LM-5000 (which is derived from the engine used in the Boeing 747, some DC-10s, and the Airbus A300), steam injection allows an increase in power from 33.1 MW to 52.5 MW and increases efficiency from 33 to 40 percent.[76] STIG units have been used in cogeneration applications, allowing for greater flexibility and efficiency when the industrial process has variable steam requirements. Intercooling, a further enhancement to STIGs, may further increase power and efficiency to nearly 50 percent. Technology transfer from future improvements in jet engines could further raise efficiency to over 50 percent.[77]

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[72] Edison Electric Institute, *1989 Capacity and Generation of Non-Utility Sources of Energy*, Washington, DC, April 1991, p. 29.

[73] Ibid., p. 1.

[74] U.S. Congress, Office of Technology Assessment, *Electric Power Wheeling and Dealing: Technological Considerations for Increasing Competition*, OTA-E-409 (Washington, DC: U.S. Government Printing Office, May 1989), pp. 46-47.

[75] "Utility Turbopower for the 1990s," *EPRI Journal*, April/May 1968, pp. 5-13.

[76] R. Williams, E. Larson, "Aeroderivative Turbines for Stationary Power," Center for Energy and Environmental Studies, Princeton, May 1988.

Turbines that can use coal or biomass gasification as fuel could be a promising technology for cogeneration applications.

Separation

Separation of two or more components in a mixture is one of the most energy-intensive processes in the industrial sector. Separations account for about 20 percent of industrial energy use. Separation of liquids is commonly accomplished through the distillation process, one of the most energy-intensive separation technologies. Other separation technologies include cryogenics, pressure swing adsorption, and mercury or asbestos diaphragm electrolytic processes.

Distillation retrofit projects offer significant potential for energy savings. For example, a small increase in the number of trays in a distillation column can reduce energy use. Also, improvements in distillation control technologies will not only enhance product quality but lower energy consumption as well. It is estimated that improvements in the distillation process can reduce energy consumption by 10 percent.[78] Further reductions in energy use are possible by using other currently available processes: the use of membranes for reverse osmosis and microfiltration, or supercritical fluid (solvent) extraction.

Membrane technology is based upon the principle that components in gaseous or liquid mixtures permeate membranes at different rates because of their molecular characteristics. Solvent extraction uses fluids with a high affinity for one component of a chemical mixture, but immiscible with the remaining components. Both technologies are used by the chemicals industry. In 1984, OTA noted that the use of solvent extraction in a synthetic fiber plant saved an estimated 40,000 barrels of oil equivalent annually.[79] Membrane separation technology is expected to capture a number of other markets, including food and beverage processing.

Catalytic Reaction

Another crosscutting technology is catalytic reaction. Catalysts are used in many industries to facilitate chemical reactions. The petroleum refining and chemicals industries rely heavily on catalysts to perform a variety of functions, including raising gasoline octane level, removing impurities, and converting low-grade hydrocarbons to higher value products.

Opportunities exist for improving energy efficiency through catalytic reaction. By increasing chemical reaction rates, lower temperatures and pressures can be used, which in turn reduce heating and compression requirements.

The discovery and use of new synthetic zeolites in catalytic processes also have contributed to energy efficiency gains in both the petroleum refining and chemicals industries. These industries have spent considerable time and effort in identifying and developing unique zeolites for use in synfuels production, petrochemical manufacture, and nitrogen oxide (NO_x) abatement.[80]

Also, energy efficiency can be improved by using catalytic reaction to recover organic acids in pulp and paper industry waste streams and in processed urban waste. Typically, these wastes are dumped because there is no method for extracting the acids unless the streams are first concentrated. A catalytic process could convert the organic acids to hydrocarbons, which can be easily separated from water.[81]

Combustion

Combustion of fossil fuels is one of the principal uses of energy in the industrial sector. The Oak Ridge National Laboratory (ORNL) estimates that more than 50 percent of industrial energy is burned in boilers and process heaters. The combustion process itself is very efficient, but inefficiencies arise in the extraction and use of the thermal energy.

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[77] Ibid.

[78] Oak Ridge National Laboratory, op. cit., footnote 25, p. 70.

[79] For additional information on oil replacement capability in the industrial sector, see U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*, OTA-E-243 (Washington, DC: U.S Government Printing Office, September 1984).

[80] Oak Ridge National Laboratory, op. cit., footnote 25, p. 67.

[81] Ibid.

A number of opportunities exist to improve energy efficiency.

The pulsed gas or condensing furnace is a demonstrated improvement in the combustion process. The furnace uses a pulsed combustion technique to induce a draft. This technique has been applied primarily to space heating systems, but there may be other applications for this technology in industry. In addition, advances in cogeneration systems for industrial and large commercial applications have the potential to increase thermal utilization efficiencies and reduce first cost.

Foremost among new technologies is atmospheric fluidized-bed combustion (AFBC). It is commercially available for industrial applications and has the potential to be widely used in cogeneration operations. Its major advantages include fuel efficiency, pollution control, and its small size. AFBC plants currently in use by cogenerators appear to be able to produce electricity at lower costs than other conventional coal plants. However, this technology is not without technology concerns. Difficulties with fuel and sorbent feeding systems are two of the most troublesome problems. According to ORNL, the AFBC, when perfected, is likely to be the coal-burning technology of choice for many industrial applications because pollution control is relatively easy to accomplish.

In addition, combustion control systems have been extensively applied to industrial operations and are expected to play an even greater role in the future. For example, in the combustion process, a given quantity of fuel requires a fixed and easily measured quantity of air. Having an excess quantity of air or fuel results in either unused air being heated or incomplete combustion of the fuel. A computer control system could optimize the fuel:air ratio by controlling the rate at which each is introduced into the combustion chamber.

Electric Motors

Electric motors are the workhorses of the industrial sector. They power pumps, fans, and compressors, and drive heating and ventilation systems. In the industrial sector, motors use 65 to 70 percent of industrial electricity.[82] Pumps alone account for about 31 percent of total electricity used by electric motors in the United States.[83] Thus, there is a significant potential for energy savings.

Standard electric motor efficiency generally ranges from 80 to 90 percent. By increasing the iron and copper content of the core and windings, respectively, energy efficiencies can be improved to beyond 95 percent. This incremental increase may not seem significant at first blush, but even small increases in electric motor efficiency could translate into considerable savings. Electric motor capital costs are only a small fraction of their operating costs.[84] A typical large industrial motor uses electricity that costs 10 to 20 times its capital cost per year. Thus, even a 1 percent gain in efficiency could translate into significant savings.[85]

Crucial to achieving greater energy efficiencies with electric drive is the ability to control motor speed. Typically, pumps and fans need to vary speed to accommodate changing process needs. This is often done by operating the pump or fan at full speed and then throttling speed with a partly closed valve or damper. When this method is used, enormous energy losses are realized. According to one estimate, industrial and commercial pumps, fans, and compressors have average annual energy losses of 20 to 25 percent.[86] The adjustable-speed drive, which is commercially available, can improve efficiency by 10 to 40 percent.[87]

New high-efficiency motors can reduce magnetic, resistance, and mechanical losses by more than 50 percent, compared to the electric motor of a decade ago. The use of higher quality materials and innovative design have made these improvements possible. Together, high-efficiency motors and adjustable-

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[82] Arnold P. Pickett, Clark W. Gellings, and Amory B. Lovins, "Efficient Use of Electricity," *Scientific American*, vol. 263, No. 3, September 1990, p. 67.

[83] Oak Ridge National Laboratory, op. cit., footnote 25, p. 68.

[84] U.S. Congress, Office of Technology Assessment, *Industrial Energy Use*, op. cit., footnote 8, p. 50.

[85] Pickett et al., op. cit., footnote 82, p. 67.

[86] Sam F. Baldwin, "Energy Efficient Motor Drive Systems," *Electricity: Efficient End-Use and New Generation Technologies and Their Planning Implications*, Thomas B. Johansson, Birgit Bodlund, and Robert H. Williams (eds.) (Lund, Sweden: Lund University Press, 1989), p. 33.

[87] Pickett et al., op. cit., footnote 82, p. 68.

Table 2-7—Estimated Energy Used To Produce Paper and Paperboard Products (In million Btu per ton produced)

Product	From 100% virgin wood	From mixed recycled paper		Change due to recycling (percentage)
	Energy use	Minimum virgin fiber content (percentage)	Energy use	
Paper products:				
Newsprint	44.33	0	34.76	–21.6
Printing paper	67.72	16	43.43	–35.9
Packaging paper	47.07	70	43.48	–7.6
Tissue paper	68.52	0	29.46	–57.0
Paperboard products:				
Liner board	14.46	75	36.28	+150.9
Corrugated board	37.22	0	36.28	–2.5
Box board	25.97	0	36.25	+39.6
Food service board	29.19	100	N/A	—
Other paper board	17.65	0	36.32	+105.8
Construction board	31.71	65	32.24	+1.7

SOURCE: T. Gunn and B. Hannon, "Energy Conservation and Recycling in the Paper Industry," *Resources and Energy* 5:243-260, 1983.

speed drives account for about half of the total potential energy savings in U.S. motors.[88]

Significant energy savings can also be realized by better matching motor size to the load, improved maintenance, and the use of controls to regulate, among other things, the electricity supplied to the motor and the torque transmitted to the machine.[89]

Pulp and Paper Industry

The pulp and paper industry is a major energy user. In 1985 (the most recent year for which data are available), the industry used 2.21 quads, making it the fourth largest energy user of primary energy in the industrial sector. A number of opportunities exist to improve efficiency. Several of the cross-cutting technologies discussed earlier can offer significant energy savings. For example, the use of computer control systems and sensors to optimize the combination of heat and chemicals can cut energy costs and improve pulp quality. In one mill, sensors and controls reduced steam requirements by 19 percent.[90]

Technologies that integrate fermentation into the conventional pulping process can also offer energy savings. They include biopulping, chemical pulping with fermentation and black liquor phase separation, and ethanol organosolv pulping. A substantial amount of research is still needed for each of these processes.

Recycling waste paper may provide further energy savings. Recycled waste paper, or secondary fiber, can be used to make various paper and paperboard products. Using recycled fiber for some paper products, like newsprint, printing paper and tissue, may require less energy. Savings can result from reducing energy demand in the process of making paper from waste paper and from a reduction in need to harvest and transport timber. However, savings could be offset by the energy needed to collect, transport, and de-ink the waste paper.[91] Based on studies done in the early 1980s, estimates of energy used to produce paper and paperboard products are shown in table 2-7.

According to the U.S. Environmental Protection Agency (EPA), paper and paperboard recovery totaled 18.4 million tons in 1988, a recovery rate of 25.6 percent. This compares to a recovery rate of 16.7 percent in 1970.[92] Paper and paperboard mills are the major consumers of secondary fiber.

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[88] Ibid.

[89] Ibid.

[90] Marc H. Ross and Daniel Steinmeyer, "Energy for Industry," *Scientific American*, vol. 263, No. 3, September 1990, p. 94.

[91] For a more in-depth discussion of recycling technologies and markets, see U.S. Congress, Office of Technology Assessment, *Facing America's Trash: What Next for Municipal Solid Waste?* OTA-O-424 (Washington, DC: U.S. Government Printing Office, October 1989).

[92] U.S. Environmental Protection Agency, *Characterization of Municipal Solid Waste in the United States: 1990 Update*, EPA/530-SW-90-042, June 1990, pp. ES-7, 11.

[93] Much of the information in this section is drawn from the OTA report, *Industrial Energy Use*, op. cit., footnote 8, pp. 99-100.

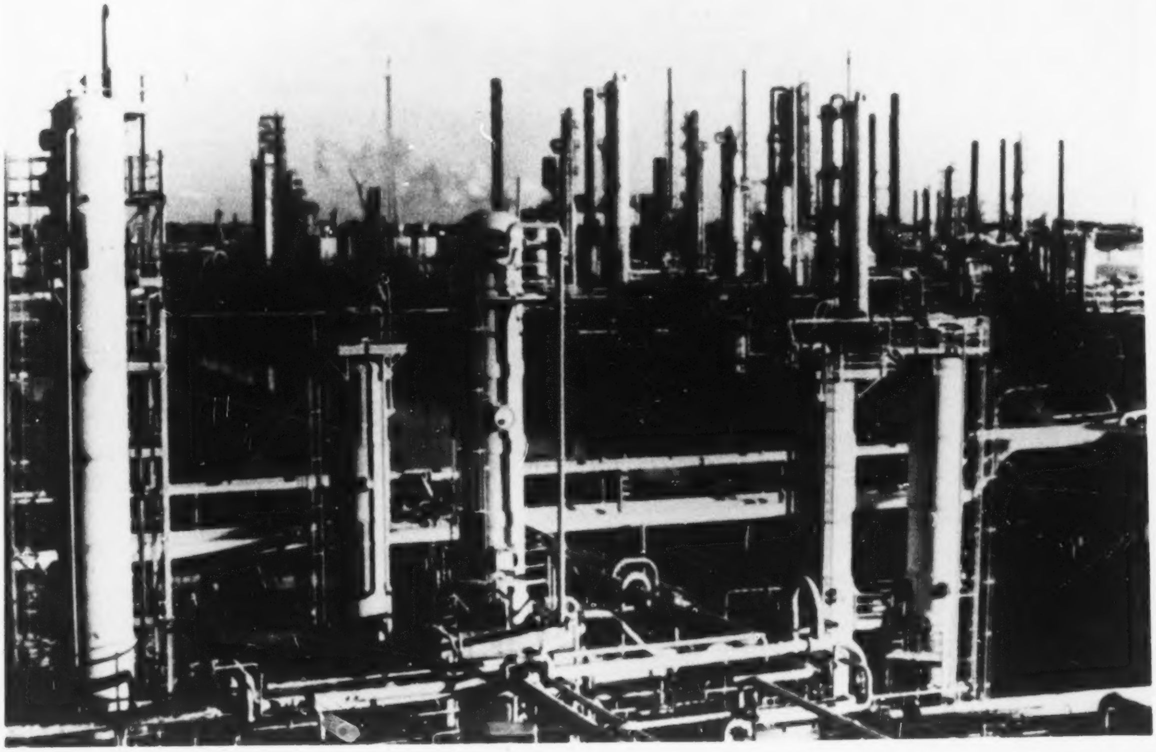

Photo credit: American Petroleum Institute and Exxon Corp.

A large petroleum refinery complex.

Petroleum Refining Industry[93]

A number of energy efficiency opportunities have been identified in the petroleum refining industry. The most productive options appear to be in the areas of improved combustion, the recovery of low-grade heat, and the use of process modifications.

The greatest single loss of energy in a refinery occurs during the final cooling of process streams. Where feasible, heated streams first could be used to heat other process streams, thus reducing the energy needed to cool. However, opportunities for recovering significant amounts of low-level heat are unlikely to be found in existing plants but in new facilities that are designed to optimize heat recovery. Opportunities focus on how to recover heat in the 200 to 250 degrees Fahrenheit range and improve heat exchange by better matching the heat source and heat sink. A 1985 survey indicated that improved heat exchange could reduce refinery energy use by about 9 percent. The survey also noted that process modifications could save up to 11 percent of energy use.[94]

Process heaters and steam boilers also offer opportunities for reducing energy use. Options include improving combustion by using stack gas analyzers and combustion control instrumentation; reducing stack gas temperatures by using air preheaters to heat incoming combustion air; and installing convection sections at the heater outlets to heat incoming feed or to generate steam.

Continued improvements in computer control systems and sensors offer energy-savings benefits as well. In addition to reducing energy use, these systems improve performance, increase output, and optimize product specifications. A number of energy management control systems are available today. One control system company estimates that energy savings of 5 to 10 percent can be realized in the petroleum refining industry.[95]

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[94] R.O. Pelham and R.D. Moriarity, "Survey Plants for Energy Savings," *Hydrocarbon Process*, vol. 64, No. 7, pp. 51-56; reported in Oak Ridge National Laboratory report, op. cit., footnote 25, p. 76.

Steel Industry

While the energy intensity of steelmaking has decreased over the years, steelmaking is still one of the most energy-intensive industries. The steel industry includes blast furnace-based integrated mills; nonintegrated minimills; and independent producers of wire, bars, and pipes who purchase and process semifinished steel.

All stages of steel production use energy to alter the chemical composition of the metal or to work the metal into useful forms and shapes. The industry has a number of options to save energy. These include the electric-arc furnace and continuous casting. The electric-arc furnace saves energy by allowing the substitution of scrap metal for iron ore. This method uses about 50-percent less energy than the blast furnace or basic oxygen furnace methods.

Continuous casting saves energy by eliminating the need for ingot stripping, heating, and primary rolling. Continuous casting reduces energy use by about 50 percent, as compared to ingot casting. Also, the yield is much greater than from ingot casting because less metal must be returned to the steelmaking process in the form of waste and unfilled ingot molds. Continuous casting increased from 12 percent in 1977 to 53 percent in 1986.[96] High product quality and yield and reductions in production costs are responsible for the increase.

A new steelmaking process—thin slab casting—is attracting the attention of the industry worldwide. This innovative process has the potential to reduce energy use and production time considerably. For example, the final slabs, which are only one-tenth of an inch thick, can be made in only 3 hours instead of as long as a week using conventional procedures. Steel industry analysts indicate that the process could change production methods throughout the industry. The first commercial use of thin slab casting in the United States is done at the NUCOR, Inc. plant in Indiana.[97]

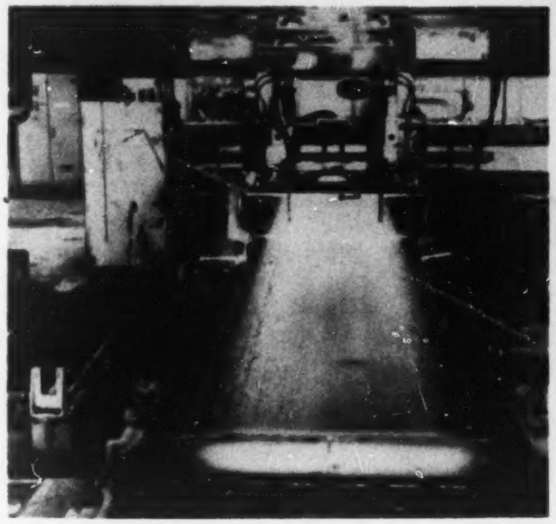

Photo credit: American Iron and Steel Institute

Steel slab emerging from a continuous slab caster.

Also, the innovative direct and ore-to-powder steelmaking processes could offer substantial energy savings. The direct steelmaking process replaces the coke-oven/blast furnace steps with one continuous process. The key to its success is effectively transferring heat from postcombustion to the bath. Another advantage of the direct steelmaking process is that it can use either iron ore or scrap. ORNL estimates that the process can reduce energy use by 20 to 30 percent and yield production rates that are two to three times higher than those of a blast furnace.[98]

The ore-to-powder steelmaking process eliminates the ore-melting process with magnetic separation and chemical leaching. ORNL estimates that this method may reduce energy use by 40 percent and decrease capital costs. The need for highly refined magnetic separation may be a technical barrier to using this method.[99]

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[95] Oak Ridge National Laboratory, op. cit., footnote 25, p. 78.

[96] Ibid., p. 86.

[97] "Making Steel Faster and Cheaper," *The New York Times*, Business Technology, Feb. 27, 1991, pp. D-6, D-7.

[98] Oak Ridge National Laboratory, op. cit., footnote 25, p. 88.

[99] Ibid.

Table 2-8—Technologies for Improving Energy Efficiency in the Steel Industry

Investment option	Energy efficiency-improving characteristics
Dry-quenching of coke	Recovers waste heat of hot coke from ovens; saves coke; reduces environmental pollution because coke is quenched in a closed system.
Coke-oven gas desulfurization	Natural gas substitute. Some loss of calorific value, but improved product quality.
Blast furnace top-gas turbine	Recovers waste energy by cogeneration. Only possible with the best high-pressure furnaces.
External desulfurization of hot metal	Saves coke by allowing lower slag volume and hot metal temperature in the blast furnace. Some energy used in desulfurization.
High-pressure blast furnace	Lowers coke consumption.
Electric-arc furnace (EAF)	Allows for increased use of scrap, thereby lowering overall energy requirements for steel production.
Water-cooled panel, EAF	Allows for higher productivity and net energy savings in melting when refractory consumption is considered.
Oxyfuel burners, EAF	Saves electrical energy and reduces melting time. Total energy consumption may be increased.
Open hearth, shrouded, fuel-oxygen lances	Reduces fuel requirements in the open hearth. May prolong useful life of open hearth.
Basic oxygen furnace (BOF) gas collection	Recovers calorific value of carbon monoxide with net energy savings.
Scrap preheating, BOF	Allows for greater use of scrap, thereby saving energy in ironmaking.
Secondary, ladle refining, EAF	Saves electrical energy by removing refining function from EAF.
Closed system ladle preheating	Saves natural gas used for preheating ladles.
Continuous casting	Increases yield, thereby decreasing overall energy requirements; saves fuel gas in ingot reheating.
Thin slab casting	Has the potential to reduce energy use and production time.
Continuous slab reheaters	Saves clean fuel gas through increased efficiency.
Continuous annealing and reheating systems	Saves clean fuel gas through increased efficiency.
Direct rolling	Saves clean fuel gas through the elimination of slab reheating.
Indication heating of slabs/coils	Allows fuel switching to electricity, conserves total energy, and increases yield.
Steam-coal injection into the blast furnace	Allows fuel switching from more expensive gas or oil. Technology should be available in 5 years.

SOURCE: Office of Technology Assessment, 1991.

A number of other opportunities are summarized in table 2-8. Many of these options require retrofitting existing equipment. Some of the energy-savings opportunities will result in additional benefits such as a reduction in environmental impacts and an improvement in product quality.

Chemicals Industry[100]

Of the four industries examined, the chemicals industry is by far the most complex. It produces several thousand products and uses the most energy of the four industries. Table 2-9 shows six of the most energy-intensive processes in chemical manufacturing.

Dramatic improvements in energy use can result from changes in physical separation. According to OTA, incremental improvements in the distillation process have achieved 25-percent energy savings in many plants.

Alternative approaches to conventional distillation include vacuum distillation, freeze crystallization, and liquid-liquid (solvent) extraction. The increased cost-effectiveness of turbocompressors and advances in vacuum pumps and cryogenic technology have vastly increased the relative attractiveness of both vacuum distillation and crystallization. The most appealing characteristic of freeze crystallization as a separation technique is that the process requires less energy. About 150 Btus are needed to freeze a pound of water compared to about 1,000 Btus to boil water in the conventional distillation process.

The most promising of the alternative approaches to conventional distillation appears to be liquid-liquid extraction, which uses a solvent with a high

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[100] Much of the information in this section is drawn from the OTA report, *Industrial Energy Use*, op. cit., footnote 8, pp. 115.

Table 2-9—Energy-Intensive Processes in Chemical Manufacturing

Electrolysis includes all industrial electrolytic processes in which electricity is used in direct chemical conversion.

Fuel-heated reaction for processes that require some type of heat to force a chemical reaction to take place can be subdivided into low- and high-temperature operations. Energy sources include steam (except for high-temperature reaction), natural gas, residual oil, distillate oil, and even fluidized-bed coal combustion. Where precise temperature regulation is required, natural gas and distillate fuel oil are used.

Distillation processes include those that require physical separation of end products from both feedstocks and byproducts by evaporation and condensation.

Refrigeration includes processes that compress and expand a refrigerant, such as ammonia or a fluorocarbon, for the purpose of cooling feedstocks or products below ambient temperatures.

Evaporation includes those processes that use passive-evaporation cooling. In general, the evaporated water is lost to the atmosphere, and the heat energy is unrecoverable.

Machine drive is used by many chemical industry processes to pump, compress, or move feedstock and end product materials. Machine drive arises from electric motors, steam turbines, or gas turbines. A subcategory of machine drive processes—mixing and blending (especially in polymerization processes)—can be very energy intensive due to the high viscosity of the materials.

SOURCE: Office of Technology Assessment, 1991.

affinity for one component of a mixture but immiscible with the remaining components. One company reported that this technology saved an estimated 40,000 barrels of oil equivalent annually.

Also, the use of membrane separation technology in the chemicals industry is growing. The technology has been used to replace other more costly separation technologies such as cryogenics, pressure swing adsorption, and mercury or asbestos diaphragm electrolytic processes. One of its major advantages is that membrane separation systems can improve product quality.

Continued improvements in energy management and advances in computer control systems and sensors will contribute to reducing energy use in the chemicals industry. ORNL estimated that the development of a full component of sensors could reduce energy use by 10 to 15 percent in both the chemicals and pulp and paper industries.[101]

OPPORTUNITIES FOR ENERGY EFFICIENCY IMPROVEMENTS IN THE TRANSPORTATION SECTOR

Since the early 1970s, efficiency improvements in the transportation sector have been dramatic. The retirement of older, less efficient vehicles and the introduction of new, more efficient models have been responsible for these improvements.

The fuel efficiency of the new car fleet doubled between 1974 and 1989. The average fuel efficiency of the light-duty fleet should continue to rise over the next decade, but the rate of improvement will be slowed by a leveling off of further efficiency improvements in new vehicles. In the current OTA "business as usual" scenario, new car fleet economy for 2001 is 33 mpg.[102]

The energy intensity of commercial air travel has been cut by more than one-half since 1970, as a result of more efficient aircraft and operations. However, efficiency improvements in heavy truck transport has been less dramatic than those achieved by passenger cars.

In recent years, concerns about urban smog have renewed interest in alternative fuels. Energy security concerns have further stimulated interest in these fuels. Alternative fuels of primary interest for the U.S. light-duty fleet are methanol, ethanol, compressed or liquefied natural gas, hydrogen, and electricity. The advantages and disadvantages of these fuels are discussed later.

Automobile Efficiency

OTA has concluded that the fuel economy of the new car fleet could range from 29.2 to 30.3 mpg in 1995. With no fuel economy standards or other new policies that could alter fuel economy, such as gasoline taxes, and no significant changes in market forces, domestically manufactured new car fleet economy will be about 28.3 mpg. Total new car fleet economy will be about 29.2 mpg, assuming a 35-percent import share. OTA believes that the industry could realistically meet a higher level—30.3 mpg—for 1995.

Significantly higher levels of fuel efficiency in the long term (by 2010) can be achieved without drastic shifts in size and performance, using only technologies that are generally expected to be commercialized shortly after the turn of the century. A fleet fuel economy of 45 mpg is possible. Some of the technology changes needed to achieve this fuel economy level include extensive use of aluminum and fiberglass reinforced plastics, 5-speed automatic transmissions, improved packaging, low-rolling resistance tires, and engine improvements, such as weight reduction of reciprocating engine components, low-friction pistons and rings, five-valve designs, and intake valve control.

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[101] Oak Ridge National Laboratory, op. cit., footnote 25, p. 69.

[102] U.S. Congress, Office of Technology Assessment, *Improving Automobile Fuel Economy: New Standards, New Approaches*, forthcoming report.

By 2010 even higher levels of fuel efficiency are possible if significant technological advances are commercially available in the 2000-10 timeframe. For example, a fleet fuel economy of about 55 mpg can be attained if maximum weight and drag reduction and packaging efficiency benefits are fully exploited. Also, the direct-injection diesel engine and turbocharging must capture 20 percent of the small car market to realize this level of fuel efficiency.

Electric vehicles can make a major contribution to efficiency gains as well as urban air quality, but only if storage technology is improved to address consumer acceptance and cost considerations. A forthcoming OTA report, *Improving Automobile Fuel Economy: New Standards, New Approaches*, discusses indepth the potential for long-term automotive fuel efficiency.

Table 2-10 lists a number of technologies whose introduction or wider use offer the potential to improve fleet fuel efficiency. In addition, there are a number of technologies at various stages of development that appear to show promise of achieving large efficiency gains. For example, new designs of a two-stroke engine for automobile applications may be capable of achieving fuel economy gains of 11 to 14 percent over conventional four-stroke engines. However, questions remain about the ability of the engine to comply with emissions standards. The advanced two-stroke engine employs direct injection of fuel and forced air scavenging. Due to forced air scavenging, the exhaust stream is lean, and the technology (three-way catalysts) for reducing NO_x emissions is not yet available. This problem may be solved with better control of airflow, and it appears possible that with further development the engine can meet future NO_x standards.[103]

Other engine designs said to hold considerable promise include direct-injection diesels and low-heat rejection engines (also called adiabatic diesels). The direct injection (DI) diesel has seen limited passenger car application in Europe. The DI diesel was rated by Volkswagen and Mercedes Benz as being 12 to 15 percent more efficient than the indirect injection (prechamber) diesel. Previous problems meeting nitrogen oxide and particulates emissions standards have been solved. Audi plans on introducing a direct injection diesel in the United States.[104] Stricter emissions requirements could pose a problem, however.

Adiabatic diesels eliminate the cooling system required by current engines and insulate cylinders and pistons to retain thermal energy within the combustion chamber and exhaust system. The ability of this and other diesel engines to meet more stringent emissions standards is in some doubt.

Heavy-Truck Efficiency

Opportunities for heavy-truck fuel efficiency gains include better aerodynamics, reduced rolling resistance, and the development of adiabatic diesels. In a conventional diesel engine, about 25 percent of the fuel energy is lost as waste heat to the cooling and lubricating of fluids, and another 35 percent is lost as waste heat in exhaust gases. The adiabatic engines offer the greatest potential for improving efficiency of freight transport. It may be capable of achieving 40 to 50 percent decreases in energy lost to waste heat.[105]

The ceramic gas turbine has also be identified as a potentially attractive heavy-duty engine because of its anticipated fuel efficiency and flexibility.

Aircraft Efficiency

Passenger travel by commercial jet aircraft has more than tripled since 1970. At the same time, energy use increased only by about [illegible]3 percent. Higher load factors, improved engine efficiencies

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[103] Energy and Environmental Analysis, "An Assessment of Potential Passenger Car Fuel Economy Objectives for 2010," contractor report prepared for the U.S. Environmental Protection Agency, February 1991, pp. 4-21, 4-22.

[104] Ibid., p. 4-24.

[105] Oak Ridge National Laboratory, op. cit., footnote 25, p. 3.

Table 2-10—Reported Efficiency Improvements for Developed or Near-Term Technology

Technology	Percent improvements over 1987 base[a]: EEA estimates (% F/E benefit)	Percent improvements over 1987 base[a]: Industry estimates (% F/E benefit)	Comment[b]
Front-wheel drive	10.0	0.5-1.0	Over 1970s rear wheel drive vehicles
Drag reduction	2.3	2.0	Per 10 percent coefficient of drag reduction
4-speed auto transmission	4.5	3.0	Widely used in 1988
Torque converter lock-up	3.0	1.5-2.0	Widely used in 1988
5-speed auto transmission	2.5	0.1-2.0	Over 4-speed automatic transmission
Electronic transmission control	0.5	0.5	For automatic transmission only
Continuously variable transmission (CVT) only	3.5	1.0-2.5	Over 4-speed automatic transmission cars only
Accessories	-0.5	1.0	Varies between 0.3 and 0.7 depending on market class
Oil (5W-30)	0.5	0.2	Already used in some large cars
Advanced tires	0.5	1.0	—
Engine improvement[c]			
Fuel injection			
—Throttle-body fuel injection	3.0	3.0	Widely used
—Multipoint fuel injection (over throttle body injection)	3.0	1.0-3.0	Widely used
Overhead camshaft	6.0	1.0-3.5	Over old overhead valve design
Roller cam followers	2.0	3.0	Widely used in domestic cars
Low-friction pistons/rings	2.0	2.0	Except for specific engines already incorporating technology
4 valves per cylinder engine	5.0	1.0-3.5	At constant performance
—4 cylinder replacing 6[d]	8.0	(-2.0)-0.5	At constant performance
—6 cylinder replacing 8[d]	8.0	1.0-3.5	At constant performance
Intake valve control	6.0	1.5-3.0	Synergistic effects with 5-speed auto/CVT

[a] The list of technology benefits cannot be summed to provide an overall benefit.

[b] Ford Motor Co.'s explanations for the significant differences between EEA and industry estimates:

Front-wheel drive—Ford's analyses and data indicate that front-wheel drive provides a small potential for fuel economy improvement because of a slight reduction in vehicle weight (60 pounds) for mid-size and smaller cars. Ford rear-wheel drive models introduced since the late 1970s are 660 pounds lighter than their predecessors. There are no technological reasons for a net efficiency gain with front-wheel drive.

4 valve over 2 valve engine—Based on U.S. Environmental Protection Agency data, Ford indicates that the average fuel economy improvement is 3 percent for equal performance engines which have incorporated 4-valve designs. The 10:1 compression ratio assumed by EEA may not be appropriate for all vehicles.

4 cylinder replacing 6 cylinder; 6 cylinder replacing 8 cylinder—Reducing the number of cylinders will reduce engine friction but increase lugging speeds. As a result, 4-cylinder engines tend to have higher idling speeds and thus lower fuel economies than 6-cylinder engines; 6-cylinder engines have slightly higher lugging speeds than 8-cylinder engines. Thus, no substantial fuel economy effect is realized by replacing 8 cylinders with 6.

Intake valve control—Systems that provide 6 percent fuel economy benefits are not suitable for typical engines because they severely compromise wide-open throttle performance.

[c] Because newly designed engines all have multiple improvements, the efficiency benefits represented by individual changes are not easily separated.

[d] 1987 Distribution: 20.5 percent—V-8; 29.5 percent—V-6; 50 percent—4 cylinder)

KEY: EEA = Energy and Environmental Analysis. F/E = Fuel efficiency.

SOURCES: Energy and Environmental Analysis, "An Assessment of Potential Passenger Car Fuel Economy Objectives for 2010," contractor report prepared for the U.S. Environmental Protection Agency, February 1991; and the Ford Motor Co.

and aerodynamics doubled seat-mile per gallon efficiencies.[106]

Aircraft efficiency will continue to improve as newer, more efficient planes replace the older, less efficient ones. For example, the Boeing 747-400 and the 737-500 are 10 to 20 percent more efficient than the equipment they replaced. Also, advances in engine technology, aerodynamics, controls, and structural materials for frames and high-temperature materials for engine components will be required to achieve improvements in fuel efficiency in the future.

Engines

The ultrahigh-bypass turbofan engine achieves greater thrust per pound of fuel used by sending as little as 15 percent of the air entering the engine shroud through the combustor. The remainder passes around the core and is accelerated by turbine engine-driven fans.

Ducted ultrahigh-bypass engines have yielded efficiency improvements of 10 to 20 percent. Unducted, or propfans, using advanced propeller designs, can achieve 20 to 30 percent efficiency improvements over current high-bypass turbofan engines. However, these advanced engines cost twice as much as current-generation high-bypass engines.[107]

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[106] Ibid., p. 5.

Improvements in engine efficiency are dependent on the development of high-temperature materials, such as metal matrix and ceramic matrix composites. These materials will allow higher turbine inlet temperatures, reduce the need for airfoil cooling, permit higher pressure ratios, and reduce engine weight. Because these ceramic materials are subject to brittleness and sensitive to flaws, they are currently not being used. To achieve advanced engines' efficiency gains, research will have to focus on high-temperature materials.

Aerodynamics and Aircraft Weight

Further reductions in aerodynamic drag and airframe weight are needed to achieve future energy efficiency improvements. Advances in computer hardware and software programs will enable engineers to optimize aircraft design. In addition, controlling air flow to minimize turbulence is necessary to improve efficiency. Some promising concepts include using suction on key wing surfaces to smooth airflow and changing wing shapes to adapt to changes in speed, altitude, and weight. Perhaps the most promising concepts involve putting grooves in the portion of the wing in front of the spar, through which air is vacuumed to reduce turbulence, with ultrasmooth wing surfaces behind to maximize the area of naturally laminar flow. It is expected that some of these wing concepts will be introduced in the early 1990s. Two of Airbus' new models will include variable-camber wings that adapt their profiles automatically during flight to match changes in weight, speed, and altitude.[108]

In addition, composite materials have the potential for reducing frame weight by 30 percent with equal or better structural strength. Today, composite materials are used only for a limited number of components such as vertical fins and the horizontal surfaces of tailplanes. It is possible that future advances could enable planes to be constructed of 80-percent composites by the 21st century.[109]

Alternative Fuels[110]

Alternative fuels of primary interest for the U.S. light-duty fleet are:

- reformulated gasoline,
- alcohol fuels—methanol and ethanol,
- compressed or liquefied natural gas (CNG or LNG),
- hydrogen, and
- electricity.

Interest in these fuels is based on their potential to address environmental and energy security concerns. The use of alternative fuels as a substitute for gasoline is being promoted by EPA, the California Energy Commission, and others as a way to address these concerns.

Much is already known about alternative fuels. Not surprisingly, each of these fuels has disadvantages as well as advantages. Aside from fuel cost, the major barrier that most alternative fuels must overcome is the need to compete with the highly developed technology and massive infrastructure that exists to support the production, distribution, and use of gasoline as the primary fleet fuel. Concerns about the performance and range of vehicles that use alternative fuels are also barriers to introduction and public acceptance. Nevertheless, each of the suggested alternative fuels has one or more features, e.g., high-octane, low emissions potential, that imply some important advantage over gasoline in powering vehicles. Table 2-11 presents some of the tradeoffs among the alternative fuels relative to gasoline.

The technologies for producing alternative fuels are still developing and changing. Ongoing research and development programs are attempting to address technical problems and reduce overall costs. For example, the success of ongoing research on low-cost manufacture of ethanol from wood waste would radically improve ethanol's environmental and economic attractiveness. The outcome of this and other research initiatives is still uncertain.

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[107] Ibid., p. 6.

[108] Ibid., p. 7.

[109] Ibid.

[110] Much of the information in this section is drawn from U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles*, OTA-E-364 (Washington, DC: U.S. Government Printing Office, September 1990).

Reformulated Gasoline

Reformulated gasoline is gasoline that has been reblended specifically to reduce exhaust and evaporative emissions and/or to reduce the photochemical reactivity of these emissions. It is appealing because it requires no vehicle adjustments or new infrastructure, aside from modifications to existing refineries. Although reformulated gasoline is now being sold in many locations in the United States, these gasolines

Table 2-11—Pros and Cons of Alternative Fuels

Fuel	Advantages	Disadvantages
Methanol	• Familiar liquid fuel. • Vehicle development relatively advanced. • Organic emissions (ozone precursors) will have lower reactivity than gasoline emissions. • Lower emissions of toxic pollutants, except formaldehyde. • Engine efficiency should be greater. • Abundant natural gas feedstock. • Less flammable than gasoline. • Can be made from coal or wood (as can gasoline), though at higher cost. • Flexfuel "transition" vehicle available.	• Range as much as one-half less, or larger fuel tanks. • Would likely be imported from overseas. • Formaldehyde emissions a potential problem, especially at higher mileage, requires improved controls. • More toxic than gasoline. • M100 has nonvisible flame, explosive in enclosed tanks. • Costs likely somewhat higher than gasoline, especially during transition period. • Cold starts a problem for M100. • Greenhouse problem if made from coal.
Ethanol	• Familiar liquid fuel. • Organic emissions will have lower reactivity than gasoline emissions (but higher than methanol). • Lower emissions of toxic pollutants. • Engine efficiency should be greater. • Produced from domestic sources. • Flexfuel "transition" vehicle available. • Lower carbon monoxide with gasohol (10 percent ethanol blend). • Enzyme-based production from wood being developed.	• Much higher cost than gasoline. • Food/fuel competition at high production levels. • Supply is limited, especially if made from corn. • Range as much as one-third less, or larger fuel tanks. • Cold starts a problem for E100.
Natural gas	• Though imported, likely North American source for moderate supply (1 mmbd or more gasoline displaced). • Excellent emission characteristics except for potential of somewhat higher nitrogen oxide emissions. • Gas is abundant worldwide. • Modest greenhouse advantage. • Can be made from coal.	• Dedicated vehicles have remaining development needs. • Retail fuel distribution system must be built. • Range quite limited, need large fuel tanks with added costs, reduced space (liquefied natural gas (LNG) range not as limited, comparable to methanol; LNG disadvantages include fuel handling problems and related safety issues). • Dual fuel "transition" vehicle has moderate performance, space penalties. • Slower refueling. • Greenhouse problem if made from coal.
Electric	• Fuel is domestically produced and widely available. • Minimal vehicular emissions. • Fuel capacity available (for nighttime recharging). • Big greenhouse advantage if powered by nuclear or solar. • Wide variety of feedstocks in regular commercial use.	• Range, power very limited. • Much battery development required. • Slow refueling. • Batteries are heavy, bulky, have high replacement costs. • Vehicle space conditioning difficult. • Potential battery disposal problem. • Emissions for power generation can be significant.
Hydrogen	• Excellent emission characteristics, minimal hydrocarbons. • Would be domestically produced. • Big greenhouse advantage if derived from photovoltaic energy. • Possible fuel cell use.	• Range very limited, need heavy, bulky fuel storage. • Vehicle and total costs high. • Extensive research and development effort required. • Needs new infrastructure.
Reformulated gasoline	• No infrastructure change except refineries. • Probable small to moderate emission reduction. • Engine modifications not required. • May be available for use by entire fleet, not just new vehicles.	• Emission benefits remain highly uncertain. • Costs uncertain, but will be significant. • No energy security or greenhouse advantage.

SOURCE: Office of Technology Assessment, 1991.

have been rushed into the market in advance of research results, and their formulations may change as ongoing research begins to identify optimal gasoline formulae.

Methanol

Methanol, which is commonly known as wood alcohol, is a light volatile flammable alcohol usually made from natural gas but can be manufactured from coal and biomass. It has an energy content of about half that of gasoline (i.e., the fuel tank has to be twice as big for the same range), an octane level of 101.5, and a much lower vapor pressure than gasoline.

The advantages of methanol include its potential to reduce urban ozone, particularly in cities that have significant smog, and its high-octane level, which allows higher (or leaner) engine air-fuel and compression ratios. Engines that operate at leaner air-fuel and higher compression ratios are more fuel efficient.

One of its disadvantages is its potentially high price in relation to current gasoline prices. The economic competitiveness of methanol continues to be a source of controversy. Estimates of methanol costs have ranged from competitive with gasoline to much higher than gasoline. OTA concludes that methanol will most likely be more expensive than gasoline in the early stages of an alternative fuels program. Without government guarantees, methanol's gasoline-equivalent price is likely to be at least $1.50/gallon. During the initial period, government guarantees could bring the cost down to as low as $1.20/gallon if natural gas feedstock costs were very low. Costs of manufacturing methanol from coal will be much higher. A recent report by the National Research Council estimates methanol-from-coal's crude oil equivalent price to be over $50/barrel, and methanol from wood, over $70/barrel.[111]

Another disadvantage of methanol is its low vapor pressure, which is problematic for cold weather starts. Also, methanol is more toxic than gasoline. It is absorbed through the skin more quickly than gasoline, but prolonged or frequent contact is necessary for acute symptoms to appear.[112]

Methanol is the most "ready" of the alternative fuels. Methanol for chemical use has been produced for many decades and thus production technology is well known. Recent attention has focused on the potential for using methanol as an automotive fuel, either 100 percent methanol or mixed with up to 15-percent gasoline. Vehicle technology capable of burning a gasoline/methanol blend has been demonstrated and could be produced in a few years. Work is continuing on improving the efficiency, driveability, and emissions characteristics of methanol-burning engines.

A number of cities and States have expressed interest in methanol use. California, for example, has a program to stimulate the development of a fleet of methanol-capable vehicles. Moreover, Congress has passed measures to stimulate development and sales of methanol-powered vehicles, and is considering legislation to develop alternative-fueled fleets in cities suffering from ozone problems.

Ethanol

Ethanol is a grain alcohol that is produced by fermenting starch and sugar crops. It has an energy content of about two-thirds that of gasoline and, like methanol, an octane level of 101.5, and a much lower vapor pressure than gasoline. Because of its high octane level, an ethanol-powered vehicle will outperform an equivalent gasoline vehicle and provide some improvement in energy efficiency.

Ethanol made from food crops would be the most expensive of the major alcohol fuels. Even so, it has managed to gain support because of its potential contribution to the agricultural economy. Every year, nearly 1 billion gallons of ethanol are added to U.S. gasoline stocks to create gasohol. The addition of small quantities of ethanol to gasoline is viewed primarily as a means to reduce carbon monoxide emissions; the use of 100-percent ethanol is viewed as a means to reduce concentrations of ozone in urban areas.

Improvements in the current production system are needed to enhance ethanol's prospects for use in transportation. SERI and others are conducting R&D on ethanol-from-biomass production processes and have achieved important advances. SERI recently formed a cooperative partnership with the New Energy Co. of South Bend, Indiana, to commercialize the process developed by SERI. SERI hopes to be able to produce ethanol-from-biomass for no more than $25/barrel of oil equivalent by the end of the decade.[113]

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[111] Committee on Production Technologies for Liquid Transportation Fuels, National Research Council, "Fuels To Drive Our Future" (Washington, DC: National Academy Press, 1990).

[112] P.A. Machiele, "A Perspective on the Flammability, Toxicity, and Environmental Safety Distinctions Between Methanol and Conventional Fuels," American Institute of Chemical Engineers 1989 Summer National Meeting, Philadelphia, PA, Aug. 22, 1989.

Currently, ethanol production is profitable because the Federal Government and about one-third of the States subsidize ethanol use by partly exempting gasohol (a 90-percent gasoline/10-percent ethanol blend) from gasoline taxes. The current Federal Government subsidy amounts to $0.60/gallon. Under certain market conditions, ethanol production may reduce Federal crop subsidies and generate secondary economic benefits to the Nation. However, it also may generate large secondary costs by promoting crop expansion onto vulnerable, erosive lands.

Natural Gas

Either compressed or liquefied natural gas can serve as an alternative fuel for vehicles. There are about 700,000 CNG vehicles in use worldwide, with the largest group in Italy. Generally, natural gas-powered vehicles are gasoline vehicles retrofitted to use either gasoline or natural gas. At current prices, dual-fueled vehicles are not cost competitive with gasoline-powered ones in most uses, and they will not become so unless oil prices rise sharply while gas prices stay low or gasoline is heavily taxed.

Most of these dual-fueled vehicles have less power and some driveability problems when powered by natural gas. The power loss and driveability problems are due to the design and/or installation of the retrofit components. Improvements in power and driveability can be realized with more sophisticated retrofit kits or in factory-built, dual-fueled vehicles. Nevertheless, dual-fueled vehicles will have a difficult time competing with gasoline vehicles or vehicles fueled with other, higher energy density fuels.

Single-fueled vehicles optimized for natural gas use are likely to be more attractive in terms of performance and somewhat more attractive in terms of cost. The cost of pressurized storage will make the vehicles more expensive (about $700 to $800 more) than a similar gasoline-powered vehicle. A natural gas-powered, single-fuel vehicle should be capable of similar power, similar or higher efficiency, and substantially lower carbon dioxide (CO_2) emissions but somewhat higher NO_x emissions than an equivalent gasoline-powered vehicle. Natural gas-powered vehicles have the potential to leak methane, which is the prime constituent of natural gas. Methane is a more powerful greenhouse gas per molecule than CO_2. In addition, the range of natural gas-fueled vehicles will continue to be unattractive compared to gasoline-fueled vehicles.

The Ford Motor Co. has done extensive work with CNG vehicles, including light-duty car and trucks, as well as heavy-duty trucks.

Hydrogen

Hydrogen, which is the lightest gas, has a very low energy per unit of volume because it is so light, but it has the highest energy content per pound of any fuel. It can be used in a fuel cell and in internal combustion engines. Hydrogen is available from a number of sources. It can be produced from hydrocarbons or from water by several processes: 1) coal gasification; 2) combining natural gas and steam (steam reforming); 3) applying high temperatures, with or without chemicals, to water (thermal and thermochemical decomposition); 4) adding an electrolyte and applying a current to water (conventional electrolysis; potential sources of the electricity are discussed in chapter 3), or by electrolyzing steam rather than water (high-temperature steam electrolysis), or by using light with a chlorophyll-type chemical to split out the hydrogen (photolysis) from water. Currently, steam reforming of natural gas is the least expensive production method.

Hydrogen's primary appeal is its cleanliness and, ultimately, its enormous resource base (water). A hydrogen-powered vehicle should emit virtually no hydrocarbons, particulates, sulfur dioxide, CO_2 or carbon monoxide, and only moderate NO_x emissions. Disadvantages of using hydrogen include its high cost, and low energy density (one-sixth that of gasoline), and the need for onboard vehicle storage. Onboard storage can be either in the form of heavy and bulky hydrid systems that will adversely affect range and performance, or in bulky cryogenic systems that will reduce available vehicle space. Both are expensive.

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[113] "SERI Signs First Cooperative R&D Agreement," *New Technology Week*, vol. 5, No. 19, May 6, 1991, p. 8.

The thermal efficiency of a hydrogen-powered engine should be at least 15 percent higher than an equivalent gasoline engine, and even higher in a fuel cell. As with other fuels, engine efficiency, performance, and emissions are interdependent, and maximizing one may increase or decrease the others. For example, operating very lean will increase efficiency but decrease power and driveability.

The development of a hydrogen-fueled fleet is still in the early stages of research. Work needs to be done on storage and delivery systems, large-scale production systems, and engines. The production system with the largest resource base—coal gasification—may be the closest to becoming fully commercial. (The Lurgi gasifier is fully commercial and some others are arguably commercial.) However, coal gasification will create substantial negative impacts from CO_2 emissions. The Cool Water integrated coal gasification combined cycle plant has performed extremely well, and the next generation technology is expected to achieve substantial improvements in cost and efficiency. The Japanese and West Germans have strong hydrogen vehicle development programs, but they have produced only a small number of prototype vehicles. Major uncertainties remain about the configuration and performance of a hydrogen engine. Also, a breakthrough in storage technology may be needed, and work needs to be done on pipeline transport because pure hydrogen will damage certain steels. Inhibiting agents to be added to hydrogen must be found, or a separate pipeline infrastructure must be built.

Electricity

The use of electricity as a fuel has several advantages: available and adequate supply infrastructure, with the exception of home charging stations, and virtually no vehicular emissions. The latter advantage can be particularly important in polluted areas. Pollutants that are emitted at generating stations that must be operated to charge the batteries often play only a minor role in urban air quality, but do contribute to problems associated with long-range pollution transport, particularly acid rain and degradation of visibility. OTA has concluded that a fleet of several tens of millions of vehicles could be supported by existing generating capacity, assuming that vehicles would be recharged at night when electricity demand from most other uses is low.

Disadvantages of electric vehicles (EVs) using current technology, in particular lead-acid batteries, include limited range, performance and capacity. Most EVs built to date have required recharging at about 100 miles or less. They are also expensive to buy and may require a special charger. DOE estimates the cost for a home recharging station to be $400 to $600.

Improving the prospects for electric vehicles in the marketplace will depend on extending their range considerably and upgrading performance in a variety of traffic situations. This can be accomplished by improving battery and powertrain technologies. The outlook for significant improvements in commercial battery technology appears promising, but uncertainties remain about costs and the environmental implications of disposing and recycling associated with battery production. The advanced batteries necessary for successful EV penetration in the urban market are too far away from mass production to allow reliable cost estimates to be made. A number of advanced battery types show promise. These include nickel/iron, nickel/cadmium, zinc/bromide, lithium/iron sulfide, sodium/sulfur, and metal-air.

Some analysts consider the nickel/iron battery very promising for the next generation of electric vehicles because it has demonstrated long lifecycle and ruggedness. This battery type, however, produces large quantities of hydrogen during recharge, uses a lot of water, and is relatively inefficient. Leading European battery developers have halted developmental work on nickel/iron batteries. The high-temperature sodium/sulfur battery offers much higher energy and power densities than lead/acid and nickel/iron types. Also, it has no water requirement, does not produce hydrogen when recharging, and has very high charging efficiencies. In the long term, the metal air battery holds some promise. This battery type has high power density and can be recharged rapidly by replacing the metal anodes, adding water, and removing byproducts. However, metal-air batteries are the farthest from commercial readiness.

A consortium was recently formed to accelerate research on EV batteries. The consortium consists of the three U.S. automakers, the Electric Power Research Institute (EPRI), and several utilities. The members have proposed a 4-year, $300-million R&D project that will focus on reducing or holding

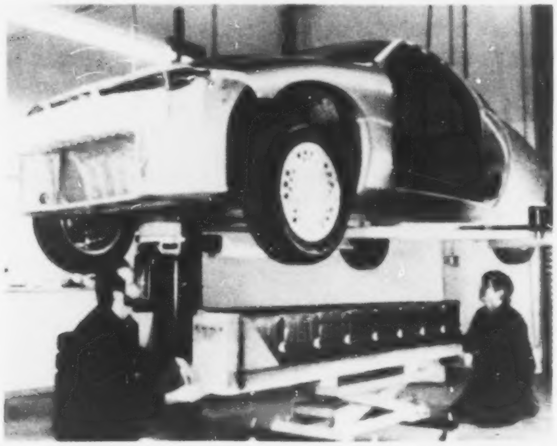

Photo credit: General Motors Corp.

General Motors' prototype electric vehicle, the Impact. The Impact's battery pack, shown being installed, takes up the center portion of the vehicle. The current range of the vehicle is over 100 miles between charges. With improved batteries—a key hurdle facing this technology—both range and efficiency would increase.

the line on battery costs, reducing weight, and increasing power capacity. DOE will provide 50 percent of the funding and participate in the project, although it is not a member of the consortium.[114]

Over the years, interest in EVs has fluctuated, but recent concerns about air quality have put this technology back on the R&D agendas of U.S. automakers. In January 1990, General Motors introduced the Impact, its most recent electric-powered car design. According to General Motors, the Impact has a range of 120 miles at average highway speeds of 55 mph. Battery charging can be done by simply plugging in an onboard charger and will require about 2 hours to complete. General Motors has not announced production plans, and cost information is not available.[115]

In addition, EPRI and the Chrysler Corp. recently announced plans to develop an electric-powered minivan suitable for passenger or light-service work. The Chrysler electric-powered minivan will have a top speed of 65 miles per hour and will be able to go 120 miles between charging. It will use a nickel/iron battery with an onboard charging unit. Chrysler hopes to begin production and marketing by 1994.[116] EPRI and General Motors also have a similar ongoing project. Production of the General Motors electric-powered van has just begun.[117]

Also, hybrid electric vehicles have been attracting attention as a way to exploit the respective advantages of gasoline and electricity. For example, in one type of hybrid, an electric motor provides the motive power, and a small gasoline-powered engine is used as an electric generator to provide the range. In another type of hybrid, a small gasoline-powered engine provides the motive power with an electric motor providing additional power. Yet another hybrid is the fuel cell-powered electric vehicle. A fuel cell is used to charge the battery and an electric motor provides the motive power. The fuel cell can operate on hydrogen or reformulated methanol.

Fuel cell hybrids are at an early stage of development. Concerns about fuel cell cost and weight and low power density represent important market barriers that will have to be addressed before the use of vehicle fuel cell systems is a viable option.

OTHER FACTORS THAT AFFECT ENERGY USE

Environmental Concerns

Recent concerns about environmental problems such as air pollution, ozone depletion, and the greenhouse effect could influence how buildings use energy and how buildings get energy. For example, the recently signed international agreement, the Montreal Protocol,[118] set out a schedule for reducing production and consumption of many chlorofluorocarbons (CFCs), the major source of ozone depletion. The Montreal Protocol requires participating countries with high CFC use per capita (greater than 0.3 kilograms) to reduce production and consumption of the most common CFCs—CFC-11 and

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[114] "The United States Advanced Battery Consortium Has Filed Notices," *Inside Energy/With Federal Lands*, Mar. 11, 1991, p. 10; and "DOE Plans Increase in Commitment to Electric Vehicle Battery R&D," Jan. 14, 1991, pp.5-6.

[115] General Motors Corp., *Impact — Technical Highlights*, Jan. 3, 1990.

[116] "EPRI Inks Contract With Chrysler To Build Electric-Powered Minivan," *Electric Utility Week*, Jan. 14, 1991, p. 7.

[117] Ibid.

[118] In response to growing international concerns about CFCs destroying stratospheric ozone, 47 nations reached agreement on a set of CFC control measures in September 1987. A significantly stronger version was adopted in June 1990.

CFC-12—by 20 percent of 1986 levels in the next 3 years, and to achieve a 50-percent reduction by 1997, and a 100-percent phaseout by the year 2000.

CFCs are used primarily in refrigeration systems, including automobile air conditioners, refrigerators, and centrifugal chillers, and in building insulation foams. In the United States, refrigeration accounts for 80,000 tons of CFCs used per year, or about 22 percent of the total. A typical refrigerator contains about 1/2 pound of CFC in its cooling systems and 2 1/2 pounds in its foam insulation.[119] CFCs are released during the manufacturing process, servicing and disposal of air-conditioners and refrigerators. Some CFCs used in insulating foams are also released during the manufacturing process, but most remain in the foam and slowly leak out over time. Therefore, a large reservoir of CFCs exist within buildings.

Alternatives to CFC insulation and refrigerants are available, and others are being developed. The chemicals industry is developing manufacturing processes for these products. In addition, alternative building designs and construction techniques can reduce the need for air-conditioning and supplemental insulation. Also, using air-conditioning technologies based on waste heat or solar energy can exploit alternative ways to maintain comfortable temperatures in buildings.

In the transportation sector, concern about urban smog and the greenhouse effect may have an impact on vehicle energy efficiency. The new more stringent emission standards, especially for NO_x will force manufacturers to trade off cost, fuel efficiency, and emissions. Historically, manufacturers have pursued a variety of strategies to achieve previous standards. For example, to meet the 1981 emissions standards, many Japanese manufacturers chose to use oxidation catalyst technology and accepted an efficiency loss of 6 to 8 percent; General Motors met the same standard with "closed loop" electronic fuel control systems with three-way catalysts that incurred no efficiency loss. The effect of the new NO_x standard (0.4 grams/mile) on fuel efficiency is not clear-cut. One OTA contractor, Energy and Environmental Analysis, Inc., estimated the potential fuel economy penalty (or gain foregone) to be about 1 percent, with significant variation possible, depending on how the manufacturers choose to trade off efficiency and costs.[120] Another OTA contractor, Sierra Research, indicates that automakers need not sacrifice efficiency if they are willing to add more catalysts, at a cost of about $100.

Environmental and, most recently, energy security concerns have renewed an interest in alternative transportation fuels as a way of reducing ozone levels in urban areas and decreasing U.S. reliance on foreign oil supplies. The oil crises of the 1970s spurred a number of Federal initiatives to supplement or replace gasoline with alternative fuels produced from domestic coal and oil shale. These initiatives, which were generally not viewed as successful, were largely abandoned in the early 1980s.

In September 1990, the California Air Resources Board approved a smog control plan that is expected to reduce hydrocarbon emissions by 28 percent, nitrogen oxide by 18 percent, and carbon monoxide by 8 percent by the year 2000. The plan phases in progressively cleaner vehicles, which could include compressed natural gas vehicles and "flexible-fuel" cars, and requires the production of electric vehicles. A number of other States are considering similar standards, which are stricter than the recently passed clean air standards.

Appliance Efficiency Standards

Appliance efficiency standards will also have an impact on energy efficiency. The Federal Government and several States have enacted minimum efficiency standards for residential appliances. Although NAECA does not set standards as high as can be achieved by the best currently available technology, it does require that standards be reviewed and allows for raising them. Standards for refrigerators, freezers, and small gas furnaces have been promulgated. Standards for other appliances are being developed.

In the 1970s, California took the lead by adopting efficiency standards for a wide range of products, including refrigerators, freezers, air conditioners, and heat pumps. Even tougher standards were adopted by the California Energy Commission in the mid-1980s. In 1987, the National Appliance Energy Conservation Act of 1987 (NAECA) set minimum

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[119] Houghton, op. cit., footnote 52.

[120] K.G. Duleep, Director of Engineering at the Energy and Environmental Analysis, Inc., personal communication.

Table 2-12—Cumulative Energy Impacts of the National Appliance Energy Conservation Amendments of 1988, 1990 to 2015

	Base case		Savings			
Department of Energy region	Electricity (TWh)	All fuels (quads)	Electricity (TWh)	All fuels (quads)	Electricity (%)	Savings all fuels (%)
New England	1,261	18.1	13	0.1	1.0	0.7
New York/New Jersey	1,833	28.6	27	0.3	1.5	1.0
Mid Atlantic	3,464	30.9	69	0.2	2.0	0.8
South Atlantic	9,112	21.8	320	0.1	3.5	0.4
Midwest	5,234	63.1	110	0.5	2.1	0.8
Southwest	4,022	23.1	135	0.2	3.4	0.8
Central	1,584	14.3	38	0.1	2.4	0.7
North Central	1,312	13.3	20	0.1	1.5	0.7
West	3,423	26.9	61	0.3	1.8	1.1
Northwest	2,087	5.8	29	(0.0)	1.4	(0.3)
Total	33,332	245.8	822	1.9	2.5	0.8

SOURCE: Lawrence Berkeley Laboratory, "The Regional and Economic Impacts of the National Appliance Energy Conservation Act of 1987," Berkeley, CA, June 1988.

efficiency (or maximum consumption) standards for many appliances[121] and will result in the least efficient appliances being taken off the market. The standards, which apply at the point of manufacture, vary according to product type and size.

The initial Federal standards are relatively stringent. For example, of all classes of refrigerators, refrigerator-freezers, and freezers, only 7 models out of 2,114 listed in the Association of Home Appliance Manufacturers directory meet the 1993 standards. Most models will have to be improved or redesigned over the next 2 years. Thus, the standards could have a significant impact on residential energy use in the future. The American Council for an Energy Efficient Economy estimated that by 2000, the standards will reduce U.S. residential energy use by about 0.9 quads/year and peak summer demand by 21,000 MW.[122]

LBL also estimated the impacts of the appliance standards on energy use. Table 2-12 shows the energy impacts by region by the year 2015. A reduction in electricity use is the primary benefit of the standards. According to LBL, the standards will save 2.8 quads of electricity; the percentage savings for all other fuels are relatively modest compared to those for electricity. The largest absolute and percentage electricity savings will occur in the South Atlantic and Southwest regions. The large savings in these regions can be attributed to the relatively greater cooling loads found in these climates and thus the prevalence of air conditioning.[123]

Other impacts of the standards include a slight shift away from central air and heat pumps in favor of room air conditioners. LBL notes that the interaction of a number of factors, including equipment costs, climate, and consumer preferences, are responsible for the shift. In addition, electric water heaters sales are expected to increase at the expense of other types of water heating equipment. The projected increase in electric water heater sales results from the higher cost of efficient nonelectric water heaters, according to LBL. Both shifts are small—about 1 to 3 percent. LBL notes that the national appliance standards will produce a net savings benefit of $25 billion.[124]

Building Energy Codes

Standardized building energy codes that define thermal characteristics have the potential to improve energy efficiency by preventing the least efficient buildings from being constructed. Currently there is little support from States and localities and the construction industry. In the 1970s there was some interest in a standardized code for new buildings.

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[121] Thirteen product types are included: 1) refrigerators, refrigerator-freezers, and freezers; 2) room air conditioners; 3) central air conditioners and central air conditioning heat pumps; 4) water heaters; 5) furnaces; 6) dishwashers; 7) clothes washers; 8) clothes dryers; 9) direct heating equipment; 10) kitchen ranges and ovens; 11) pool heaters; 12) television sets; and 13) fluorescent lamp ballasts.

[122] Geller, op. cit., footnote 13, p. 30.

[123] Joseph H. Eto et al., Lawrence Berkeley Laboratory, *The Regional Energy and Economic Impacts of the National Appliance Energy Conservation Act of 1987*, June 1988, pp. 15, 16, and 19.

[124] Ibid.

Congress enacted legislation in 1976 requiring the development of the Building Energy Performance Standards, a mandatory national code based on performance standards. However, before the building energy performance standards were finalized in 1983, the law was modified to be mandatory only for Federal buildings.

The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) also promulgates standards. ASHRAE standards, which typically require a 3-year payback period, are regularly updated. Compliance is voluntary; most States adopt but poorly enforce the ASHRAE standards. The Federal buildings standards are nearly identical to ASHRAE's new Series-90, but they, too, are seldom enforced.

ASHRAE previously released standards in 1975 and 1980. The 1980 standard was estimated to result in energy reductions in commercial buildings of 12 to 29 percent compared to buildings constructed in the late 1970s. Modifications to lighting contributed about half of the total savings. The new ASHRAE standard is expected to provide 20- to 25-percent energy savings in commercial buildings over the previous ASHRAE code. It is important to note, however, that the average energy efficiency of new buildings in most States exceeds the 1980 ASHRAE standards.

Some States, especially on the west coast, require tighter standards and enforce them. Other States are considering novel approaches to encouraging energy efficiency. For example, the State of Massachusetts is considering hookup fees and rebates to encourage energy efficiency in new commercial buildings. Commercial buildings (50,000 square feet or larger) that will use more electricity per square foot than average would be charged a stiff utility hookup fee. Buildings designed to use less electricity than average will receive a rebate. The fees collected from the owners of the less-energy efficient buildings are rebated to the energy efficient building owners.[125]

Standards are equally important for existing buildings. Some cities in California have recently enacted conservation ordinances for existing residential and commercial buildings. These ordinances stipulate that a building must be upgraded to minimum standards before the title is transferred.[126]

Corporate Average Fuel Efficient (CAFE) Standards

The purpose of the CAFE standards is to boost fuel efficiency beyond what the manufacturers believe the market alone warrants. From 1973 to 1987, automobile fuel efficiency gains were impressive. The current CAFE standards establish a uniform efficiency target of 27.5 mpg that must be achieved by all manufacturers regardless of the mix of vehicles in their fleets. The efficiency target, however, is subject to revision, pending ongoing U.S. Department of Transportation rulemaking. The current standard places a more difficult technological burden on companies that sell a mix of vehicle sizes than on companies selling small vehicles only. Automakers who focus on small cars will have more flexibility than the "full line" manufacturers to introduce features that are attractive to consumers but are fuel inefficient. OTA indicates that a higher fuel economy level could be achieved if all automakers were required to improve efficiency to the maximum extent possible.

Electric Utility Programs—Demand-Side Management

Demand-side management programs can result in greater investments in energy efficient equipment and building shell improvements. Utilities in all regions of the country are using demand-side management programs to reduce load and to possibly defer the need for future generating capacity additions. In addition, State public utility commissions and energy offices have supported these programs. EPRI forecasts that by the year 2000 demand-side management programs could reduce summer peak demand by 6.7 percent (45 GW) and annual electric use by 3 percent.[127]

Demand-side management programs include activities undertaken by a utility or customer to influence electricity use. Activities undertaken by utilities include rate programs (time of use or time of day), interruptible rates, real-time pricing, no demand charge under certain conditions, and use of "smart" demand meters. The time of use rate is the most frequently used.[128]

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[125] Bevington and Rosenfeld, op. cit., footnote 35, pp. 85-86.

[126] Ibid.

[127] Electric Power Research Institute, "Impact of Demand-Side Management on Future Customer Electricity Demand: An Update," EPRI CU-6953, September 1990, p. v.

A growing number of utilities offer financial incentives to commercial, industrial, and residential building owners who invest in energy efficient equipment, such as appliances, space conditioning systems, lighting products, and motors. Rebates were the most popular form of financial incentive. Most utilities use minimum efficiency levels as the unit of measure for the rebates.

A national survey completed in 1986-87 found that about 35 to 50 percent of the Nation's utilities have some type of energy efficiency rebate program. The most frequently stated purpose of the rebate program was to promote energy efficiency, followed by peak load reduction. According to the survey, commercial and industrial rebate programs reduced, on average, peak demand by 13.6 MW per year. Residential rebate programs reported peak demand savings, on average of 9.7 MW per year. The average peak demand reduction for all programs was 21 MW per year.[129]

Another survey, conducted by ORNL, found that many utilities increasingly recognize the commercial buildings sector as a significant source of untapped savings in energy and corresponding peak demand. Rebate programs for commercial buildings are likely to expand and proliferate in the future because of the potential cost and energy savings of such initiatives, according to ORNL.

And, there are indications that utilities are willing to go beyond financial incentives to encourage investment in energy efficiency. For example, Pacific Gas and Electric (PG&E), with help from the Natural Resources Defense Council (NRDC), developed a $2 billion, 10-year program aimed at promoting energy efficiency. The program includes a state-of-the-art facility for demonstrating and developing energy efficient technologies, which is expected to open in late 1991, a research study to identify economical ways to improve energy efficiency, consumer education programs, and, of course, financial incentives. PG&E's goal is to cut peak demand growth by 75 percent (2,500 MW) for the 1990-2000 period.[130]

Under this innovative program, PG&E shareholders and customers are expected to benefit. After efficiency measures are installed, dollar savings are estimated. For every dollar saved, shareholders will received 15 cents. Customers will receive 85 percent of the savings through rate reductions. However, customers will pay slightly higher rates in the short term to cover the costs of the program.[131]

Oil Supply and Price Uncertainties[132]

Short-term or even long-term interruptions in the availability of Middle Eastern crude oil always remain a possibility. Oil supply interruptions and the accompanying increases in oil prices weaken the U.S. economy, increase inflation, and decrease personal disposable income. After the Iraqi invasion of Kuwait in early August 1990, crude oil prices jumped from about $18/barrel to a high of more than $40/barrel and then back down again. The initial hike in oil prices contributed to the U.S. recession. There was also some concern at the time that escalating oil prices would trigger a global recession.

While the demand for petroleum is generally sensitive to price, other factors can also influence consumption. Existing plant and equipment and the potential for sizable shifts in fuel preference can limit the ability to save oil. Also, personal disposable income and demographic changes can also have an impact on oil use. Thus, there is considerable uncertainty about the rate of investment in energy saving equipment during an oil disruption. In fact, the strain of high oil prices on personal disposal income may actually minimize investment in more energy efficiency equipment. For example, residential and commercial oil users may be unable to invest in new heating and hot water equipment at a time when their heating bills are straining their finances. Or, consumers may defer the purchase of new, more efficient automobiles.

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[128] J.O. Kolb and M.S. Hubbard, "A Review of Utility Conservation Programs for the Commercial Building Sector," ORNL/CON-220, Oak Ridge National Laboratory, Oak Ridge, TN, 1988, p. 26.

[129] "A Compendium of Utility-Sponsored Energy Efficiency Rebate Programs," report prepared by the Consumer Energy Council of American Research Foundation and the American Council for an Energy Efficient Economy for the Electric Power Research Institute, EPRI EM-5579, Palo Alto, CA, December 1987.

[130] Testimony of Greg M. Rueger, Senior Vice President and General Manager, Electric Supply, Pacific Gas and Electric, before the U.S. Senate Committee on Energy and Natural Resources, Regarding Titles III and IV of the National Energy Security Act of 1991, Concerning Energy Efficiency and Renewable Energy, Feb. 26, 1991; and "PG&E Launches $2-Billion Energy Saving Program," *Los Angeles Times*, Business Section, Mar. 14, 1991, p. D1.

[131] Ibid.

[132] For a detailed discussion of U.S. vulnerability to oil disruptions, see U.S. Congress, Office of Technology Assessment, *U.S. Vulnerability to an Oil Import Curtailment*, OTA-E-243 (Washington, DC: U.S. Government Printing Office, September 1984), and a forthcoming update.

In any event, the increasing U.S. reliance on foreign oil supplies, particularly the insecure sources of supply in the Middle East, and the potential for large increases in oil prices should be strong incentives to evaluate the energy efficiency progress that has been made to date and to continue to look for energy-saving opportunities. During the Arab oil embargo of 1973-74, crude oil prices quadrupled, and more than doubled again during the Iranian crisis of 1978-80. These disruptions and the resultant increases in oil prices changed U.S. thinking about the importance of energy. Historically, the U.S. simply shifted from one supply source to another as declining supplies or other concerns shifted consumer preferences. Little research attention and policy concern were given to energy conservation until after the 1973 oil embargo. However, rising oil prices and the specter of insufficient supplies that followed 1973 set in motion a flurry of research, demonstration, and development programs, government initiatives, and private commitment to pay attention to the cost of energy and to lower that cost through improved efficiency in design and process. Federal spending for conservation R&D, for example, increased from about $3 million in fiscal year 1974 to $406 million in fiscal year 1980 (1982 constant dollars),[133] but has since declined. The result of all of these efforts was that the U.S. economy became considerably more energy efficient, across all sectors.

Fuel Switching

Fuel switching away from oil was another response to the oil disruptions of the 1970s. It became an important way of restoring services formerly supplied by oil and enhancing the reliability of fuel supplies. Many energy users in the industrial and utility sectors now have the capability to switch between alternative fuel sources quickly—often with only a twist of a knob—to take advantage of relative differences in fuel prices and availability. Today, there are more than 100,000 dual-fuel units in the United States. About two-thirds can burn gas continuously.

Typically, utilities switch from oil to gas when gas prices are lower and vice versa. For example, in 1979 and 1987, utilities switched to natural gas because prices were lower. And, in 1986 the reverse was true.

Additions to fuel switching capability will depend on a number of factors, including seasonal and regional demand, availability of supplies, price considerations, and technical constraints. Much fuel switching capability has already been realized. Since the mid-1970s, many oil-fired generating plants have been converted to gas- or coal-fired units. Those that have not been converted generally include units that are too small to justify conversion, or cannot be converted because of environmental or financial constraints, or lack coal-burning handling and storage capability. In addition, inadequate fuel supplies or storage may preclude switching on an immediate or continuous basis.

Given these considerations, DOE estimates that natural gas could at a minimum replace about 85,000 barrels of oil per day immediately.[134] The DOE estimate could be higher when several new pipeline projects come on line. The projects are being developed to supply domestic and Canadian gas to the northeast and California. Also, acid rain legislation will make natural gas a more attractive fuel option for reducing sulfur emissions.

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[133] Congressional Research Service, *Energy Conservation: Technical Efficiency and Program Effectiveness*, IB85130, updated Jan. 10, 1991, attached tables.

[134] U.S. Energy Information Administration, Department of Energy, *Electric Power Monthly*, "Petroleum Fuel-Switching Capability in the Electric Utility Industry," September 1990.

Chapter 3

Technologies for Energy Supply and Conversion

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Chapter 3

Technologies for Energy Supply and Conversion

Despite stable energy supplies and prices, recent events in the Middle East and declining domestic oil production have triggered concern over the long-term adequacy of U.S. energy supplies. In addition, environmental considerations, e.g., global warming and high ozone levels in urban areas, will continue to have an impact on energy supply choices.

A variety of technologies (table 3-1) show promise for replacing and/or extending the Nation's oil and gas resources and providing other options. Included are technologies for improving coal combustion, electric power generation, and nuclear and renewable energy supply options. This chapter begins with a brief summary of U.S. energy resources and ends with a discussion of nontechnical factors that could affect U.S. supply options.

U.S. ENERGY SUPPLY

Fossil fuels continue to dominate the U.S. energy market. Table 3-2 shows U.S. energy production by source from 1970 to 1989. Coal accounts for the largest share of domestic energy production today. The U.S. Energy Information Administration (EIA) indicates that there are enough coal reserves to sustain current levels of production for more than 200 years. Most of the coal (62 percent) is mined east of the Mississippi River, but Western coal has been increasing its share since the mid-1960s. The growth in Western coal production is partly a result of environmental concerns over Eastern high-sulfur coal. Also, surface mining, which is more prevalent in the West, has a higher productivity rate than underground mining.[1]

Coal has been the United States' major energy export. Japan, Italy, and Canada are our leading customers. Together they accounted for about 41 percent of total coal exports in 1989.[2] In the United States, electric utilities are the largest market for coal.

The United States has used more than half of its oil and gas, and estimates of undiscovered recoverable resources are inherently uncertain. Oil production in the contiguous States has been declining since the mid-1970s, and in 1989 Alaskan production declined for the first time since 1981. The low price of oil over the past 4 years has contributed to this decline.

Exploration was also affected by the low price of crude. According to the EIA, exploration indicators showed a dramatic drop in the number of seismic crews, operating rigs, and completed wells.[3] More oil will be discovered in the United States, but it is very unlikely that new discoveries will reverse the long-term decline.

This decline in production translates into a greater dependence on oil imports. In 1989, petroleum net imports reached 41 percent of total consumption. Saudi Arabia, Canada, Venezuela, and Nigeria are our biggest suppliers. These and other oil producing countries have used less than 35 percent of their resources. According to a recent resource assessment, the Middle East has the majority of the identified reserves for the world, enough oil to continue production for 124 years. It is likely that the United States will continue to import Middle Eastern oil for many decades.[4]

Since the early 1980s, domestic natural gas production has been declining. New wells have been added, but at a much slower pace than previously. Texas, Louisiana, and Oklahoma produce more than two-thirds of the U.S. total. Most of the natural gas is from onshore and State offshore wells, but about one-fourth is produced from leased Federal offshore areas.[5]

Recent estimates indicate that demand for natural gas will continue to exceed growth in domestic production. In 1989, natural gas imports accounted

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[1] U.S. Energy Information Administration, Department of Energy, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, p. 177.

[2] Ibid., p. 178.

[3] Ibid., p. 1.

[4] C.D. Masters et al., "World Resources of Crude Oil, Natural Gas, Natural Bitumen, and Shale Oil," paper presented at World Petroleum Congress, Houston, TX, 1987; in Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference?* "Supply Technology," ORNL-6541/V2/P2, vol. 2, Part 2, December 1989, pp. 2-4.

[5] U.S. Energy Information Administration, op. cit., footnote 1, p. 158.

Table 3-1—Major Technologies for Energy Supply and Conversion

Technology	Availability	Comments
Oil		
Deepwater/arctic technologies	C,R	Existing technologies that are promising for deepwater areas include guyed and bouyant towers, tension leg platforms, and subsea production units. Advances in material and structural design critical; innovative maintenance and repair technologies important.
Enhanced oil recovery techniques	C,R	Widely adopted over the past two decades.
—thermal recovery		
—miscible flooding		
—chemical flooding		
Oil shale and tar sands	C,N	Uneconomic at present oil prices.
—Surface retorting		
—Modified in situ		
Natural gas		
—Hydraulic fracturing	C	Very complex process; not well understood although successful for some formations. Key to unlocking unconventional gas reserves.
Coal		
—Atmospheric fluidized-bed combustion (AFBC)	N,R	Small-scale units commercial. Utility-scale AFBC in demonstration stage.
—Pressurized fluidized-bed combustion (PFBC)		PFBC is less well developed; pilot-plant stage.
—Integrated gasification combined cycle (IGCC)	N	Demonstration stage. Primary advantages are its low emissions and high fuel efficiency.
—Flue-gas desulfurization (FGD)	C	Mature technology; considerable environmental advantages.
—Sorbent injection	C,N	Commercially available control technology. Can remove nitrogen oxides up to 90 percent.
—Staged combustion	R	Has potential to remove up to 80 percent of nitrogen oxides.
Nuclear		
—Advanced light water reactor	C	Incorporates safety and reliability features that could solve past problems; public acceptance uncertain.
—Modular high-temperature gas reactor (MHTGR)	N,R	Improvements to familiar technology; incorporates passive safety features; design of modular reactor completed.
—Power Reactor Inherently Safe Module (PRISM)	R	Conceptual designs expected to be completed this year.
Electricity		
—Combined cycle (CC)	C	Conventional CC is a mature technology; advanced CC is in demonstration stage.
—Intercooling Steam Injected Gas Turbine (ISTIG)	N	Pilot-plant stage.
—Fuel cells	R	Several types being developed. Fuels cells that use phosphoric acid as electrolytes are in demonstration stage. Molten carbonate and solid oxide are alternative electrolytes that are less developed. Late 1990s availability, at the earliest.
—Magnetohydrodynamics (MHD)	R	Difficult technical problems remain, especially for coal-fired MHD systems.
—Advanced batteries	R	Research and development needed in utility-scale batteries to improve lifetime cycles, operations maintenance costs. Promising batteries are advanced lead, zinc-chloride and high-temperature sodium-sulfur..
—Compressed air energy storage (CAES)	C	First U.S. plant (110-MW) to begin operation in 1991; owned and operated by Alabama Electric Cooperative, Inc.
Biomass		
—Thermal use	C	Use of biomass by utilities is usually uneconomical and impractical.
—Gasification	C	Anaerobic digestion used commercially when biomass costs are low enough. Methane production from biomass not yet competitive with conventional natural gas unless other factors considered.
—Production of biofuels	C,R	Research being done on wood-to-ethanol/methanol conversion processes. Could be demonstrated by 2000.
Geothermal	N	Single-flash system used extensively. Little commercial experience with dual flash. Binary cycle system may be available in 40- to 50-MWe range by 1995.
—Dual flash		
—Binary cycle		
Solar thermal electric		
—Central receiver	R	Several plants built, including one in California; 30-MW plant in Jordan is major project today.
—Parabolic solar trough	C	Several commercial plants built in California; additional capacity planned appears to be marketable.
—Parabolic dishes	N,R	Testing being conducted in new materials and engines such as free-piston sterling engine.
Photovoltaic	R	Improvements needed to make photovoltaic cells economic in the bulk power market advances in microelectronics and semiconductors can make photovoltaics competitive with conventional power by 2010.
—Concentrator system		
—Flat-plate collector		
Wind power	C	Renewable source closest to achieving economic competitiveness in the bulk power market. Current average cost is 8 cents/kWh.
Ocean thermal energy conversion (OTEC)	R	Research focused on closed and open cycle systems; no commercial plants designed. May be competitive in 10 years for small islands where direct-generation power is used. Use of OTEC domestically for electric power is unlikely except for coastal areas around Gulf of Mexico and Hawaii.

KEY: C = commercial; N = nearly commercial; R = research and development needed.

SOURCE: Office of Technology Assessment, 1991.

Table 3-2—Production of Energy by Source (quadrillion Btu)

Year	Coal	Natural gas[a]	Crude oil[b]	Natural gas plant liquids	Hydroelectric power[c]	Nuclear electric power[d]	Other	Total
1970	14.61	21.67	20.40	2.51	2.63	0.24	0.01	62.07
1971	13.19	22.28	20.03	2.54	2.82	0.41	0.01	61.29
1972	14.09	22.21	20.04	2.60	2.86	0.58	0.03	62.42
1973	13.99	22.19	19.49	2.57	2.86	0.91	0.05	62.06
1974	14.07	21.21	18.57	2.47	3.18	1.27	0.06	60.84
1975	14.99	19.64	17.73	2.37	3.15	1.90	0.07	59.86
1976	15.65	19.48	17.26	2.33	2.98	2.11	0.08	59.89
1977	15.76	19.57	17.45	2.33	2.33	2.70	0.08	60.22
1978	14.91	19.49	18.43	2.25	2.94	3.02	0.07	61.10
1979	17.54	20.08	18.10	2.29	2.93	2.78	0.09	63.80
1980	18.60	19.91	18.25	2.25	2.90	2.74	0.11	64.76
1981	18.38	19.70	18.15	2.31	2.76	3.01	0.13	64.42
1982	18.64	18.25	18.31	2.19	3.27	3.13	0.11	63.90
1983	17.25	16.53	18.39	2.18	3.53	3.20	0.13	61.21
1984	19.72	17.93	18.85	2.27	3.35	3.55	0.17	65.85
1985	19.33	16.91	18.99	2.24	2.94	4.15	0.21	64.77
1986	19.51	16.47	18.38	2.15	3.02	4.47	0.23	64.23
1987	20.14	17.05	17.67	2.22	2.59	4.91	0.24	64.82
1988	20.74	17.49	17.28	2.26	2.31	5.66	0.24	65.97
1989	21.35	17.78	16.12	2.16	2.77	5.68	0.22	66.07

[a] Dry natural gas.
[b] Includes lease condensate.
[c] Electric utility and industrial generation of hydroelectric power.
[d] Generated by electric utilities.
[e] Other is electricity generated for distribution from wood, waste, geothermal, wind, photovoltaic, and solar thermal energy.

NOTE: Sum of components may not equal total due to independent rounding.

SOURCE: U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990; and *Monthly Energy Review April 1991*, DOE/EIA-0035(91/04), Apr. 26, 1991, p. 19.

for almost 7 percent of total gas consumption and are expected to increase in the near term. Canada is our major supplier with Algeria providing smaller amounts. The United States also exports small amounts of gas to Japan.[6]

Electricity has steadily increased its share of the total U.S. energy market from 24.4 percent in 1970 to about 36 percent in 1989. In the past 15 years, the electric utility industry has had financial problems due to excess capacity, as powerplants ordered in the 1970s came online and demand growth fell below industry's expectations. Excess capacity is disappearing as demand grows and local shortages may occur, but overall, resources appear to remain adequate. In fact, according to the North American Electric Reliability Council, most regions have more than enough capacity to meet their increasing needs for several years. This projection rests on two assumptions: 1) that electricity use increases at projected rates, and 2) that existing and planned capacity is available as projected.

Since the mid-1970s, coal- and nuclear-powered generation have displaced substantial quantities of petroleum and natural gas. Growth in oil and gas use began to slow in the 1970s, and consumption decreased during the first half of the 1980s. In 1989, coal accounted for 56 percent of electric utility consumption, compared to 9 percent for natural gas and 6 percent for petroleum.[7]

Nuclear power accounted for about 19 percent of electricity generation in 1989,[8] and preliminary U.S. Department of Energy (DOE) estimates indicate that nuclear power's share increased by 1 percent in 1990.[9] Nuclear power's contribution to electric power generation has increased steadily since the mid-1960s. The number of operable nuclear generating units reached an all-time high (112) in 1989, but only a few of the planned new units remain under construction, and no additional units are planned.[10] Uncertainty about electricity demand, increases in construction costs and rising interest rates, and questions about nuclear safety and waste disposal have contributed to the decline of nuclear power as a supply option.

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[6] Ibid.

[7] Ibid., p. 203.

[8] Ibid., p. 219.

[9] U.S. Energy Information Administration, *Electric Power Monthly March 1991*, DOE/EIA-0226(91/03), March 1991, p. 23.

Renewable energy resources account for a small share of total energy supplies today. Hydroelectric power is by far the greatest contributor, accounting for about 2.7 quads (quadrillion British thermal units) in 1989.[11] However, concerns about the environment and our dependence on imported oil have renewed interest in alternative sources of energy. The conversion of solar energy to electricity, using either photovoltaics or thermal-electric technologies, offers an exciting but not yet competitive resource under traditional economic terms. Continued improvements in performance and cost of electric power from wind turbines and geothermal technologies are also expected.

TECHNOLOGICAL OPPORTUNITIES FOR IMPROVING FOSSIL FUEL SUPPLIES

Oil, natural gas, and coal are the primary energy sources in the United States because they are convenient and economical. They are expected to remain so in the foreseeable future. Technologies that can extend the production of oil and gas or replace them with equivalent fuels from coal are the focus of this section. In addition, new technologies for improving the combustion of coal are examined.

Petroleum

Conventional Production Technology

Primary conventional techniques utilize natural forces to coax the oil to the surface. Pressurized water can be used to displace oil, or oil can be drained downward from a high elevation in a reservoir to wells at lower elevations. However, most of the reservoir's oil remains in place. Techniques can be used to augment natural forces. These include injecting fluids (commonly, natural gas) into an oil reservoir. This is commonly known as secondary recovery. Conventional primary and secondary recovery technologies can recover about one-third of the oil in place.

Drilling techniques also can be used to improve recovery. Geologically targeted infill drilling, for example, involves drilling reservoirs at closer than normal intervals. Each reservoir has to be geologically targeted in order for this recovery method to be economical. The Oak Ridge National Laboratory (ORNL) estimated that the geologically targeted infill-drilling technique will recover an additional 8 percent of the original oil in place.[12]

In addition, the use of horizontal drilling in offshore production is rapidly expanding. The advantages of using horizontal drilling are improved recovery, better drainage, and the ability to drill and complete several wells from one offshore production platform.[13]

Deepwater Technologies[14]

Most of the undiscovered oil and gas reserves in the United States are expected to be found offshore or onshore Alaska. The Alaska Outer Continental Shelf (OCS) region includes about 1,300 million acres. The U.S. Department of the Interior has leased 8.2 million acres since 1976.[15]

The technologies to explore and produce the oil and gas in these remote locations have developed, and will probably continue to develop, in an evolutionary fashion. The oil and gas industry moved its onshore technology offshore—first onto piers, then onto seabed-bound platforms, and finally onto floating vessels as it ventured into deeper water. Technological advances continue to be made as new deepwater fields are discovered. From the mid-1960s to mid-1980s, technological developments improved deepwater exploratory drilling from a maximum depth of 632 to 6,952 feet.

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[10] U.S. Energy Information Administration, op. cit., footnote 1, p. 219.

[11] Ibid., p. 7.

[12] Oak Ridge National Laboratory, op. cit., footnote 4, p. 12.

[13] Ibid.

[14] Most of this discussion is based on the OTA report *Oil and Gas Technologies for the Arctic and Deepwater*, OTA-O-270 (Washington, DC: U.S. Government Printing Office, May 1985). The reader is referred to this report for a more indepth discussion of the technological, economic, and environmental factors that affect exploration and development of energy resources in the Arctic regions.

[15] U.S. Department of the Interior, Minerals Management Service, *Alaska Update: September 1988-January 1990*, MMS90-0012, 1990, p. 1.

Thus far, nearly all offshore fields have been developed using fixed-leg production platforms. These platforms can probably be designed for water depths of 1,575 feet or more. However, as depths increase, structures become larger, more substantial, and thus more expensive. The cost and size of these platforms may limit their application to greater depths.

Existing technologies that are promising for deepwater areas include guyed and buoyant towers, tension leg platforms, and subsea production units. (See figure 3-1.) All but the subsea units are flexible structures that "give way" under wind, wave, and current forces. Current technologies can be extended to depths of about 8,000 feet without the need for major breakthroughs.

The guyed tower is a tall, slender structure that requires less steel than a fixed-leg platform. Guy lines or anchor lines are used to resist lateral forces and to hold the structure in a nearly vertical position. Exxon installed the first guyed tower in the Gulf of Mexico. The buoyant tower is also a tall, slender structure. Large buoyancy tanks, rather than guy lines, maintain the tower's vertical position.

A tension leg platform is a floating platform that is fixed by vertical tension legs to foundation templates on the ocean floor. Buoyancy is provided by pontoons. Bouyancy in excess of the platform weight maintains tension on the legs. This technology can be used economically in deep water. Its primary disadvantages are the operational complexity relative to fixed platforms and its limited deck load capacity. The first tension leg platform was installed in 1984 by Conoco in the North Sea.

Subsea production systems are also used to develop deepwater fields. Wells are drilled from a floating rig and completed on the sea floor. There are two types of subsea production systems: wet or dry. The wet system is relatively insensitive to water depth and can be installed in deep water in much the same manner as in shallow water. It is limited by the depth capability of the floating drilling unit. In the dry system, the well head is housed in a dry, atmospheric chamber on the sea floor. Flowline connection and maintenance work can be done by workers inside the chamber. Personnel are transported to and from the chamber in a diving bell. Most subsea production systems are single well. The oil is produced through a flowline to shore or to a fixed or floating platform. One of the limitations of this system is the need to have surface facilities to process and transport the oil.

A number of production-related technologies are crucial to the development of deepwater areas. Advances in materials and structural design and foundation engineering are critical. Innovative techniques for the installation, maintenance, and repair of platforms and pipelines are also important. Deepwater pipeline systems will involve adaption from conventional pipelaying techniques, but new approaches will have to be developed to overcome problems, e.g., buckling by long unsupported span lengths, higher strain levels, and severe seas. Support operations, e.g., diving and navigation, will be increasingly important. Because human diving capability is limited, manned vehicles and remote-controlled unmanned vehicles will be increasingly used for these purposes.

Arctic Production[16]

Offshore exploration of the Arctic region began in the mid-1970s. Since then, the pace of activity and technological advances have increased significantly. See table 3-3 for the status of North Slope exploration and production projects.

Because of the severe environment, oil and gas development in the Arctic region is a major technological challenge. Production systems must withstand exposure to severe and corrosive conditions for the life of the oil fields, which is usually 20 years or more. Ice conditions, including duration, thickness, and movement, are perhaps the most critical of the environmental considerations.

The type of exploratory drilling rig and the technology needed for field development are determined by site and environmental conditions. Most offshore exploratory drilling has been done from manmade (gravel) islands. However, gravel islands could be prohibitively expensive in water deeper than 50 to 60 feet. The alternatives are steel and concrete structures built as caissons or complete bottom-mounted units. There are many designs for these structures, including conical shapes to reduce ice forces.

Additional research is needed on ice properties, movements, and forces under a range of conditions

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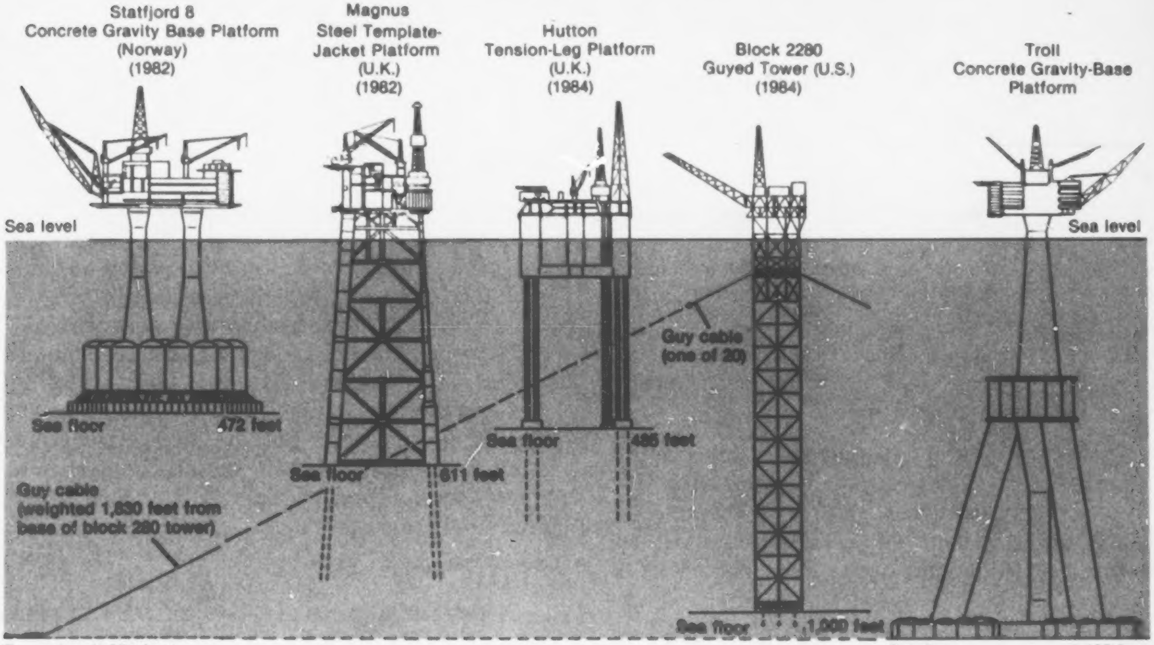
[16] Arctic is defined as the Beaufort, Chukchi, and Bering Seas north of the Aleutian Islands.

Figure 3-1—Production Platform Technologies for Frontier Areas


Statfjord 8
Concrete Gravity Base Platform
(Norway)
(1982)
Magnus
Steel Template-Jacket Platform
(U.K.)
(1982)
Hutton
Tension-Leg Platform
(U.K.)
(1984)
Block 2280
Guyed Tower (U.S.)
(1984)
Troll
Concrete Gravity-Base Platform
Sea level
Sea level
Sea floor
472 feet
Sea floor
611 feet
Sea floor
485 feet
Guy cable
(one of 20)
Guy cable
(weighted 1,830 feet from base of block 280 tower)
Sea floor
1,000 feet
To anchor (1,350 feet)
Sea floor
1,122 feet

SOURCE: U.S. Congress, Office of Technology Assessment, *Oil and Gas Technologies for the Arctic and Deepwater*, OTA-O-270 (Washington, DC: U.S. Government Printing Office, May 1985), figure 3-3.

that are likely to be encountered. Increased surveillance from satellites and aircraft is needed to provide real-time data. These data are important for structural design purposes, logistics, and tanker transportation design and planning. In addition, more information is needed on oceanographic and meteorological processes and seismicity.

Exploration Technology

Many experts believe that most of the United States' low-cost oil has been discovered and produced. Increasingly, new production must come from oil finds in hostile, expensive frontier areas or from high-technology, high-cost oil recovery operations. Improvements in technologies that measure gravity and magnetism and record seismic information are critical to selecting favorable drill sites. Seismography, which was originally developed to record earthquakes, is now used as a prospecting tool. A seismograph provides the only direct way of acquiring subsurface structural information without drilling wells. The petroleum industry has recently developed new recording instruments called seismometer group recorders.

Another improvement, the borehole gravimeter, can measure rock densities as far as several hundred feet away from the borehole. The borehole gravimeter can also be used to indicate rock content—whether it is oil, dry gas, or water. This information is key to understanding structural conditions.

Continual advances in computers and electronic equipment have made it possible to analyze larger geographical areas more easily and interpret data more accurately.

Enhanced Oil Recovery

As noted earlier, conventional recovery techniques recover on average about 34 percent of the oil in place. Improvements can be made by using enhanced oil recovery techniques. The techniques most commonly used are thermal recovery, miscible flooding, and chemical flooding. They have been widely adopted over the past two decades. The

Table 3-3—Status of Alaska State Coastal Exploration, Development, and Production Projects

Unit/field/ prospect	Designated operator	Lease sale	Sale date	Reserves in place	Reserves recoverable	Exploratory drilling	Delineation	Development	Primary production	Secondary production	Tertiary production	Status as of December 1989
Colville Delta (Texaco)	Texaco			N/A	N/A	X						No activity.
Duck Island Unit (Endicott)	BP Exxon	Joint Federal-State lease Sale	09/10/69 12/12/79	1,000 MMBO	0.8 Tcf 375 MMBO	X	X	X	X			Maintain production at 100,000 bpd.
Gwydyr Bay Unit	ARCO	State Sale 23	09/10/69		30-60 MMBO	X	X					Total of 12 wells. Renewed interest in prospect by Vaughn Petroleum (et al.) in 1987. Drilled two wells both P&A. Reduced reserve estimates and wait for higher oil price. Conoco resigns as operator.
Kaktovik Prospect (KIC well)	Chevron	Negotiated with Arctic Slope Regional Corp.	11/83	N/A	N/A	X						Tight hole.
Kuparuk Unit	ARCO	State sale 14	07/14/65	4,400 MMBO	1070 MMBO	X	X	X	X	X	X	Steady production at 280,000 bpd; 39 percent oil field depleted.
Lisburne Field	ARCO	State sale 14	01/24/67	3,000 MMBO	165 MMBO	X	X	X	X	X		Recoverable reserve estimates reduced 50 percent.
Mine Point Unit	Conoco	State sale 14	07/14/65		60 MMBO	X	X	X	X			Shutdown since January 1987; Conoco received drilling permits. Plans to begin production again.
Niakuk Prospect	BP	State sales 14 and 18	07/15/65 01/24/67	145 MMBO 88 Bcf	58 MMBO 35 Bcf	X	X	X				Army Corps of Engineers rescinded earlier causeway denial. BP must submit additional data on causeway.
North Star	Amerada Hess			N/A	150 MMBO	X	X	X				Initial stages of development; proposed unit agreement.
Pt. McIntyre	ARCO	State sale 14	07/14/65	N/A	300 MMBO	X	X					Drilled three wells in 1988 and 1989 with approved drilling permits for three more.
Point Thomson Unit	Exxon	State sale 18	01/24/67		350 MMBO 5 Tcf	X	X					Will drill another delineation well spring 1990.
Prudhoe Bay Unit	ARCO/BP	State sale 13, sale 14, sale 18	12/09/64 07/14/65 01/24/67	23.5 BBO	9.4 BBO 29 Tcf	X	X	X	X	X	X	Enhanced recovery techniques and sale good reservoir management will keep production at 1.5 MMbpd through 1989 with slower production decline now anticipated. Eileen West End Field started producing in June 1988. Peak production will be 60,000 to 70,000 bpd in 1990 from 76 wells.
UGNU Field in Kuparuk/ Prudhoe/Mine	ARCO	State sale 13, sale 14, sale 18	12/09/64 07/14/65 01/24/67	6-11 BBO	0	X						Drilled production test well April 1989. Loose sandstone reservoir and low American Petroleum Institute gravity present major technological hurdles.
West Sak Field	ARCO	BF(SM)	12/12/79	15-25 BBO	750 MMBO	X	X					ARCO filed application with ACOE to build gravel pads. Subsequently, delayed citing economic impact.

KEY: ACOE = Army Corps of Engineers; BBO = billion barrels of oil; Bcf = billion cubic feet; bpd = barrels per day; MMBO = million barrels of oil; Tcf = trillion cubic feet.

SOURCE: U.S. Department of the Interior, *Minerals Management Service Alaska Update*, September 1988-January 1990, MMS90-0012,1990, p. 33.

use of enhanced recovery methods is dependent on the characteristics and location of the field.

Thermal Recovery Process—The viscosity of crude oil varies considerably. Some crudes flow like road tar, others as readily as water. High viscosity makes oil difficult to recover with primary or secondary production techniques. Viscosity of most oils decreases as the temperature increases. The purpose of thermal oil recovery processes is to heat the oil to make it flow more easily. The oil can be heated by injecting hot water, steam, or hot gases into a well.

More than 90 percent of thermal recovery projects in the United States are in California, where heavy crudes are common. According to ORNL, total oil recovery using primary pumping and thermal recovery can exceed 50 percent of the available oil in the field. The cost of the thermal process can range from $3 to $18 per barrel.[17]

Miscible Gas Flooding—Another common approach to enhanced oil recovery is miscible gas flooding. Miscible gas, which is usually either a hydrocarbon mixture (natural gas) or carbon dioxide (CO_2), is injected into a well. Inert gases, such as nitrogen, can also be used for gas flooding. The gases act as solvents, forming a single oil-like liquid that can flow through a reservoir to other wells more easily than the original crude. Hydrocarbon gas flooding is economical when there is a large supply of available natural gas. For example, hydrocarbon flooding accounts for about 10 percent of oil production in Alberta, Canada, where there is a large supply of natural gas associated with the production of oil. Also, unused natural gas can be injected back into the field to increase oil yield. This is being done in the Alaskan North Slope fields.[18]

In the contiguous United States, the use of hydrocarbon flooding is less common because of the lower availability of and greater demand for natural gas. CO_2 flooding is more common. CO_2 is injected under such high pressure that it becomes like a liquid which is miscible with oil. More than 60 percent of gas flooding projects in the United States use carbon dioxide. The cost of CO_2 flooding ranges from about $10 to $23 per barrel.[19]

Chemical Flooding—A number of other processes involve injecting chemicals (e.g., surfactants and polymers) into the water-flooded field to alter the properties of the liquids. Polymers are added to the field to increase the viscosity of water. Surfactants are used to alter the surface properties of the oil-water and permit the removal of oil from capillary regions of a field. Chemical flooding processes are not yet well developed. Moreover, oil yields from these processes are difficult to predict. The cost of polymer flooding can be low but so too can the yield of additional oil. One estimate of the cost of surfactant flooding is between $15 and $30 per barrel. In addition, the degradation of chemicals can be a problem.[20]

Microbial enhanced oil recovery is a variation of chemical flooding. Microorganisms, which are introduced into a reservoir, produce detergent-like materials that would perform much the same function as polymers and surfactants. This technology is not well developed and a number of uncertainties remain. For example, any bacteria developed would need to be monitored for potential environmental impacts.

Although enhanced oil recovery is a particularly attractive technology for extending known oil supplies, it is hampered by a number of uncertainties. These include the inability to predict the amount of oil that can be recovered and the difficulty in characterizing the field. These uncertainties may limit the use of enhanced recovery techniques to those projects where improvements in recovered oil are sufficient enough to take the risk. Current research and development (R&D) programs are focusing on understanding the physical processes taking place in an enhanced recovery operation and quantitatively examining the structure and flow patterns of the field.

Oil Shale and Tar Sands Production Technologies

Oil shale is the second most abundant fossil energy resource in the United States. North American oil shale resources in place are estimated at 5,600 billion barrels. How much is recoverable is not known.[21] At present oil prices, recovery of these resources is uneconomic.

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[17] Oak Ridge National Laboratory, op. cit., footnote 4, pp. 12-13.

[18] Ibid., p. 13.

[19] Ibid.

[20] Ibid.

Oil shale consists of a porous sandstone that is embedded with a heavy hydrocarbon known as kerogen. Because the kerogen already contains hydrogen, a liquid shale oil can be produced from the oil shale simply by heating the shale to break the kerogen down into smaller molecules. This can be accomplished by a surface retort process, a modified in situ process, or a so-called true in situ process. Liquid shale oil can be upgraded relatively easily to crude oil.

In the surface retort method, oil shale is mined and placed in a metal reactor where it is heated to produce the oil. This method is best suited to thick shale seams near the surface. In the modified in situ process, an underground cavern is excavated and an explosive charge detonated to fill the cavern with broken shale rubble. Part of the shale is ignited to produce the heat needed to crack the kerogen. Liquid shale oil flows to the bottom of the cavern and is pumped to the surface. The modified in situ method is used in thick shale seams deep underground. In the true in situ process, holes are bored into the shale and explosive charges are ignited in a particular sequence to break up the shale. The rubble is then ignited underground, producing the heat needed to convert the kerogens to shale oil. The true in situ method is best suited to thin shale seams near the surface.

The surface retort method requires the mining and disposal of larger volumes of shale than the modified in situ method. The true in situ method requires very little mining. However, high oil yields of relatively uniform quality are difficult to achieve using the modified and true in situ methods. This is due to difficulties in controlling underground combustion and ensuring that the heat is efficiently transferred to the shale.

Since 1980, Unocal has constructed a commercial-size oil shale project in Colorado. The underground mine produces 13,500 tons of crushed ore per day, and the retorting complex is designed to produce 10,000 barrels of oil per day. In 1988, the complex operated for several months at 5,000 to 6,000 barrels per day at a cost of $45/barrel.[22]

Tar sands resources in North America are estimated at 315 billion barrels, most located in Canada. Oil from tar sands is being commercially produced at the huge Athabasca deposit in Alberta, Canada. In the United States and Canada, much of the resource is not minable at the surface and will have to be produced using in situ extraction technologies. R&D efforts have focused on the chemical and physical properties of tar sands and the physics of mobilizing and extracting the bitumen constituents.[23]

Natural Gas[24]

Conventional Gas Production

The way in which gas is produced depends on the properties of the reservoir rock and whether the gas occurs by itself or in association with oil. Hydrocarbons in the reservoir rock migrate to the producing well because of the pressure differential between the reservoir and the well. How readily this migration occurs is a function of the pressure of the reservoir and the permeability of the reservoir rock. When the reservoir rock is of low permeability, the rock may be artificially fractured to form pathways to the wellbore. This is accomplished either with explosives or by hydraulic means, pumping a pressurized fluid into the well.

Production can continue as long as there is adequate pressure in the reservoir to propel the hydrocarbons toward the producing well. If gas is the only propellant, the reservoir pressure decreases as the gas is extracted and is eventually no longer sufficient to force the hydrocarbons toward the well. In a water-driven reservoir, water displaces the hydrocarbons from the pores of the reservoir rock, maintaining reservoir pressure during production and improving the recoverability of the hydrocarbons. In most reservoirs, gas recovery is high compared to oil recovery. A recovery value of 80 percent is typical.

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[21] Ibid., p. 9.

[22] Ibid., pp. 18-19.

[23] Ibid.

[24] Much of the information in this section is drawn from the OTA report *U.S. Natural Gas Availability: Gas Supply Through the Year 2000*, OTA-E-245 (Washington, DC: U.S. Government Printing Office, February 1985). The reader is referred to this report for a more indepth analysis of conventional and unconventional gas supplies.

When gas occurs in association with oil, it can be reinjected into the reservoir to maintain pressure for maximum oil recovery. Gas is also reinjected when there are no pipeline facilities available to transport it to market.

Enhanced Gas Recovery

At some reservoirs, recovery efficiencies are much lower than 80 percent. For example, recovery rates for water-driven reservoirs found along the Texas and Louisiana Gulf Coast are known to be 50 percent or less. These poor recovery rates result from water encroachment and the subsequent trapping of gas in water-driven reservoirs and from uncertainties about the characteristics of the reservoir. A better understanding of gas field characteristics and improvements in drilling and production technologies would increase recovery efficiencies.[25]

Unconventional Gas Production

Unconventional gas includes tight sands, Devonian shale, methane from coal, and geopressured brine. The Devonian shales and methane from coal are the best understood of the unconventional resources and appear to have the most near-term potential for contributing to supply. Estimates of total recoverable unconventional gas resources are 600 trillion cubic feet (Tcf) for tight sands, 400 Tcf for Devonian shale, and 400 Tcf for coal seams.[26] If natural gas is to play a significant role in reducing CO_2 emissions, it will be important to find ways of recovering "unconventional" gas resources.

Tight gas is natural gas that is found in formations of sandstone, siltstone, silty shale, and limestone. These formations are characterized by their very low permeability. There are two distinct types of tight formations: blanket formations, which extend laterally over large areas, and lenticular formations, which consist of many small discrete reservoirs, often shaped like lenses. Figure 3-2 shows the main tight gas-bearing basins in the contiguous United States.

Over the past several decades, rising gas prices, tax policies, and improvements in production technology have encouraged gas producers to exploit more lower permeability formations. Because of poor flow characteristics of reservoir rock in tight formations, economically recoverable gas can be achieved only by increasing permeability by fracturing the rock surrounding the wellbore. This fracturing is most commonly hydraulic, which involves pumping a fluid under high pressure into the well until the rock breaks down. Sand or other materials are added to the fluid to serve as wedges to prevent the fractures from closing.

The fracturing process in tight formations is very complex and not well understood. It is difficult to tell what a fracture will do or what it has done even after the well is producing or proved unproductive. Despite these uncertainties, fracturing has been successful, at least for the blanket formations. Large-scale fracturing of lenticular formations has not been very successful. Lenticular formation developers have tended to use shorter, less expensive fracturing treatments, which may imply lower gas recovery.

Devonian shale gas is produced from shales formed about 350 million years ago—during the Devonian period. Devonian shales occur primarily in the Appalachian region, Illinois, and Michigan. The shale gas occurs as free gas in the fractures and pores of the shale and also as gas physically bound to the shale (adsorbed gas).

As with tight sands, Devonian shale production depends on well stimulation to overcome the naturally low permeability of the reservoir and open up pathways for the gas to flow to the wellbore. Unlike tight sands, however, successful Devonian gas production depends on the well intersecting a natural fracture network, either directly or through an induced fracture.

Stimulation by the use of explosives has been prevalent in production history, and more sophisticated explosive techniques may be promising for future development. Also, new fracturing fluids that avoid formation damage have been used for Devonian shale development. These include gas-in-water emulsions, nitrogen, and liquid carbon dioxide. The gas-in-water emulsions have been popular, but nitrogen has also grown in use for shallow wells because it does not cause formation damage.

Methane from coal is a byproduct of the coal formation process that is trapped in the coal seams. Methane is found in all coal seams, although its

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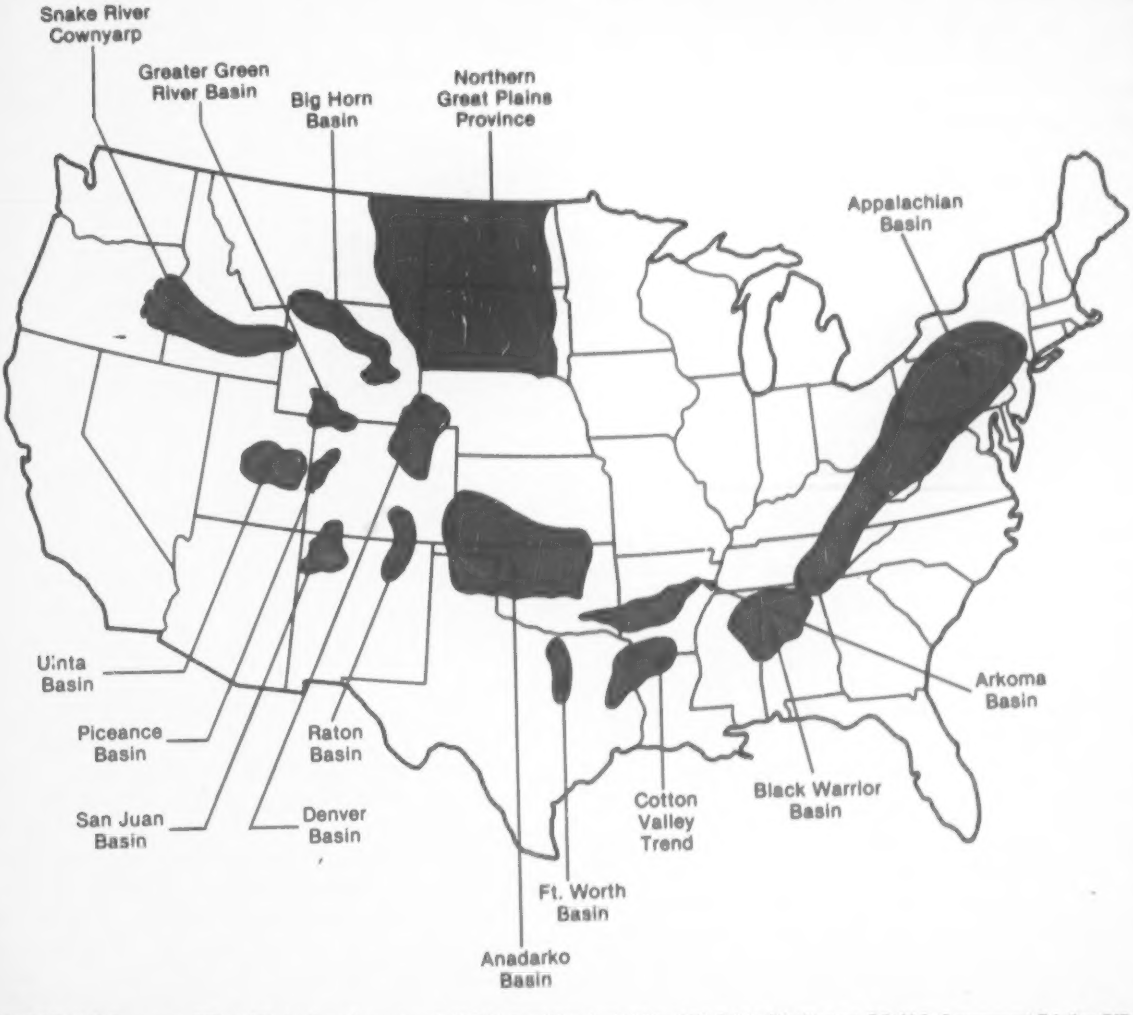
[25] Oak Ridge National Laboratory, op. cit., footnote 4, p. 17.

[26] Ibid., p. 8.

Figure 3-2—Location of Principal Tight Formation Basins


Snake River
Cownyarp
Greater Green
River Basin
Big Horn
Basin
Northern
Great Plains
Province
Appalachian
Basin
Uinta
Basin
Piceance
Basin
Raton
Basin
San Juan
Basin
Denver
Basin
Cotton
Valley
Trend
Black Warrior
Basin
Arkoma
Basin
Ft. Worth
Basin
Anadarko
Basin

SOURCE: U.S. Congress, Office of Technology Assessment, *U.S. Natural Gas Availability*, OTA-E-245 (Washington, DC: U.S. Government Printing Office, February 1985), figure 26.

amount per unit volume or weight of coal tends to be proportional to the carbon content of the coal. Anthracite and bituminous coal have high carbon content and higher gas content. Methane content also increases with depth.

Because coal in itself is essentially impermeable, methane production depends on intersecting the natural fracture network to provide pathways for the gas to flow to the well. A second condition of economic production of methane is to promote the desorption of the gas from the coal into the fracture system by reducing the pressure in the fractures. Many coal seams contain water and thus the reservoir pressure is partially a hydrostatic pressure caused by groundwater. Reducing pressure usually involves pumping water out of the seam. The water removal also increases the relative permeability of the gas in the fracture network, allowing more gas to flow to the wellbore. The effective recovery of methane may require drilling wells on relatively close spacing and pumping water from them rapidly and simultaneously in order to maximize the pressure drop. This practice of close spacing is in sharp contrast to the wide spacing used in conventional gasfields.

A variety of methods can be used to enable wells to intersect the naturally vertical fracture network. Horizontal wells may be drilled from within a working mine or a specially drilled shaft. The latter method is expensive. Vertically drilled wells may be slanted toward the horizontal, so as to run parallel to and within the coal seam. Hydraulic fractures can also be used to connect the wellbore to the fracture system.

Other unconventional gas sources include geopressured brines and gas hydrates. Geopressured brines are found deep within the Earth under high pressures and temperatures. They are found primarily in the Gulf Coast region of the United States. In order to produce the gas, the brines are pumped to the surface, the gas is removed, and the brines are disposed. Gas hydrates are an icelike mixture of gas and water, called a clathrate, which forms under certain temperature and pressure conditions often found in water depths greater than 100 feet and under permafrost. The resource is potentially huge and may be augmented by free gas trapped under the impermeable hydrate. It should be noted, however, that gas hydrates are unstable. If they warm just a bit, natural gas is released, contributing to global warming.

Future efforts to recover tight gas, Devonian shale gas and methane from coal will depend on advances in well stimulation technologies and improvements in drilling patterns. Also, additional research is required to understand gas production mechanisms and develop an exploration rationale for identifying attractive drilling sites.

Coal

Coal is burned to produce heat, which in turn is used to generate steam for process heat or the production of electricity. The heat may be used directly in industrial processes or space heating. Coal also can be used to effect chemical reactions such as the reduction of iron ore or the production of lime, or indirectly as a source for the production of synthetic gaseous or liquid fuels.

Direct Combustion

Three major factors influence the way coal is burned: 1) the size of the facility, 2) the environmental standards the facility is required to meet, and 3) the characteristics of the coal to be burned. Most coal is still burned in **pulverized coal-fired boiler furnaces**. Raw crushed coal is pulverized and blown with air into large furnace cavities, where the cloud of coal dust burns much like a fuel gas. The heat is transferred to water, which boils to generate steam. Over the years, improvements in combustion technology have resulted in larger plants that can operate at higher temperatures and pressures, and therefore higher efficiency. Further efficiency gains are likely to be incremental. In recent years, much of the attention has been focused on reducing emissions.

Conventional technology can meet existing emission standards, especially in large facilities. Emerging technologies are likely to be necessary to meet stricter standards, especially in small- and medium-size facilities. They also may permit substantial gains in efficiency.

Fluidized-bed combustion (FBC) technology[27] offers an emerging alternative. Its basic principle involves the feeding of crushed coal for combustion into a bed of inert ash mixed with limestone or dolomite. The bed is fluidized, or held in suspension, by injecting air through the bottom of the bed at a controlled rate great enough to cause the bed to be agitated much like a boiling fluid. The coal burns within the bed, and the sulfur oxides (SO_x) formed during combustion react with the limestone or dolomite to form a dry calcium sulfate. This capability to capture sulfur in situ reduces or eliminates the need for expensive add-on sulfur removal equipment. According to the National Acid Precipitation Assessment Program (NAPAP) report, the FBC system can remove up to 95 percent of sulfur dioxide (SO_2) and up to 80 percent of the nitrogen oxide (NO_x) emissions.[28]

There are two basic types of fluidized combustors: the atmospheric fluidized-bed combustor (AFBC) and the pressurized fluidized-bed combustor (PFBC). The AFBC operates at atmospheric pressure. Small-scale AFBCs already are used commercially around the world for process heat, space heat, various other industrial applications, and electrical generation.

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[27] Much of this section is drawn from the OTA report *New Electric Power Technologies: Problems and Prospects for the 1990s*, OTA-E-246 (Washington, DC: U.S. Government Printing Office, July 1985).

[28] National Acid Precipitation Assessment Program, *NAPAP Report 25, Technologies and Other Measures for Controlling Emissions: Performance, Costs and Applicability*, Washington, DC, 1990, p. 6-36.

The PFBC operates at high pressures and therefore can be more compact than the AFBC. It can run exhaust heat through the turbines as well as the steam cycle. The PFBC also may produce more electricity for a given amount of fuel. Despite these potential advantages, the PFBC has more serious technical obstacles to overcome and is less well developed than the AFBC. For example, the corrosion of gas turbine blades is a primary concern for combined cycle PFBCs. In addition, fuel and sorbent feed control may be difficult. The first PFBC/combined cycle plant began testing in March 1991. The test is expected to last 3 years. The demonstration plant is one of the flagship projects in DOE's Clean Coal Demonstration Program.[29] It is unlikely that more than a few PFBC commercial units could be completed and operating before the end of the century, although the PFBC's longer-term potential is quite promising.

The primary types of AFBCs are bubbling bed and circulating bed. The bubbling-bed AFBC is characterized by low gas velocities through the bed. The result is a bed from which only the smaller particles are entrained with the gas. Conversely, the gas flow velocities through the circulating bed are rapid. Neither technology has been built to produce electricity on a scale (100 to 200 megawatts (MW)) that is attractive to utilities. The bubbling-bed technology is the older of the two and thus greater operating experience in the United States. Also, the bubbling-bed combustor can be readily retrofitted to some conventional boilers. The disadvantages include fuel-feed problems, which are encountered in larger units. With the circulating-bed combustor, the fuel-feed problem may be less serious. However, there is less experience operating circulating-bed AFBCs.

More than 1,000 MW of existing coal-fired capacity are being converted to the AFBC technology. And, about 100 smaller AFBC systems for nonutility applications are either generating power or on order.[30] It is expected that larger utility-scale AFBC units will be ready for use by the mid-1990s. OTA estimated that the capital cost of a large AFBC is comparable to conventional coal-fired plants equipped with scrubbers—$1,260 to $1,580/kilowatts of electric power output (kWe).

OE has selected two AFBC projects to promote utility use. One project, a circulating fluidized-bed system replaces three small coal-fired boilers with 110 MW of capacity. The second project involves repowering a 250-MW Southwestern Public Service Co. facility. Also, DOE has selected two projects to demonstrate the PFBC technology. The capital cost of a 500-MW PFBC is estimated to be about $1,350 or $1,750/kWe for a 200-MW plant.[31]

The **integrated gasification combined cycle** (IGCC) technology is another alternative to conventional coal-fired plants. In the IGCC process, coal is mixed with air and steam at high temperatures, which causes the coal to gasify to a mixture of hydrogen, carbon monoxide, and hydrogen sulfide, called syngas. The ash is separated and disposed of or used. The sulfur in the coal is converted into hydrogen sulfide, which eventually can be converted to elemental sulfur or some solid waste material. The cleaned gas is burned in a combustion turbine. The hot exhaust gases that exit the combustion turbine generate steam, which can then drive a steam turbine to produce electricity. The name "combined cycle" refers to the use of both gas-fueled combustion and steam turbines in the system.

An IGCC system's major advantages are its very low rate of emissions and its fuel efficiency. It also requires less water than a conventional coal-fired steam plant, and because of the modular design, construction time is shorter. One of the areas where additional research is needed is in fuel gas treatment.

Hot gas cleanup systems remove sulfur and nitrogen compounds and particulates from the fuel gas without cooling and then reheating the gas. These compounds are very abrasive and must be removed to prevent turbine blade and component failure. Existing gas cleanup technology must operate at relatively cool temperatures. Switching from a cold- to hot-gas cleanup system could increase efficiency by 3.6 percent,[32] but many difficult technological problems must be overcome.

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[29] "PFBC and a New Era for Coal Arise From Mothballed Plant," *Power*, vol. 135, No. 4, April 1991, p. 103.

[30] *Environmental and Energy Study Conference Special Report*, "Clean Coal Technologies: A Key Clean Air Issue," Oct. 31, 1989, p. 7.

[31] National Acid Precipitation Assessment Report, op. cit., footnote 28.

[32] Oak Ridge National Laboratory, op. cit., footnote 4, p. 30.

One of the biggest IGCC demonstration projects is the 100-MW Cool Water Plant located in Daggett, California. It has been operating successfully since 1984 and has demonstrated the ability to meet stringent California pollution standards using both low-sulfur Western coal and high-sulfur Eastern coal.

In the Cool Water process, a coal-water mixture is injected into a pressurized, oxygen-fed gasifier. A medium grade fuel is produced. The sulfur in the coal is converted mostly into hydrogen sulfide, and the nitrogen oxide is converted into molecular nitrogen. The hot gases heat the tubes of water, creating steam. The steam is used to drive turbines to produce electricity. The gas and slag are then separated. A sorbent is used to remove 97 to 99 percent of the sulfur from the gas produced from coal.[33] The cleaned gas is burned in a turbine at a low temperature, which reduces NO_x production.

Capital costs for an IGCC system could range from $1,200 to $2,350/kWe (net). For smaller units (250-MW range), costs are expected to be higher, about $1,600 per kWe. The Electric Power Research Institute (EPRI) estimates a plant cost of $1,630/kWe for a 500-MW IGCC. The gas production and purification facilities will account for about 40 percent of total costs. Operating and maintenance costs could range from 6 to 12 mills/kilowatt hour (kWh).[34]

Technologies for Controlling Emissions[35]

Typically, emissions are reduced by four methods: 1) cleaning coal to reduce sulfur content, 2) switching to low-sulfur coal, 3) using wet flue-gas and 4) using combustion controls for NO_x emissions. According to NAPAP, almost all high-sulfur Eastern coal is cleaned before being burned. Physical coal cleaning reduces SO_2 by 10 to 30 percent, but reductions of 50 percent can be achieved.

New advanced coal cleaning technologies can remove up to 65 percent of the sulfur content in coal. These technologies include advanced froth (multistage) flotation, electrostatic separation, and oil agglomeration. The costs of removing SO_2 using the multistage flotation process are estimated to range from $131 to $268/metric ton removed, depending on the sulfur content of the feed coal. The costs for the oil agglomeration process ranges from $221 to $472/metric ton removed. These technologies are expected to be commercial by the mid-1990s, but none will be adequate to meet New Source Performance Standards by themselves.

The removal of SO_2 from stack gases is termed **flue-gas desulfurization** (FGD). Devices commonly referred to as scrubbers are used in this process. The function of the scrubber is to bring the flue gases, which contain SO_2, into contact with a chemical absorbent, such as lime, limestone, magnesium oxide, etc. FGD technologies are characterized as wet or dry, depending on the state of the reagent as it leaves the absorber.

There are two FGD processes: nonregenerable (throwaway) or regenerable. In the throwaway process, the absorbent and the SO_2 react to form a product which is disposed of as sludge or solid. The regenerative process recovers the absorbent in a separate unit for reuse in the scrubber and generally produces a product with market value, such as elemental sulfur or sulfuric acid. A great majority of the FGD processes employed by the utility industry are wet, nonregenerable systems that use limestone or lime.

Wet scrubbing for new plants can remove up to 95 percent of SO_2. The technology does not remove NO_x, but this can be accomplished by incorporating low-NOx burners into the design of a new plant. Capital and operating and maintenance costs of the wet limestone FGD technology are dependent on the type of coal burned and the amount of sulfur removed. For example, the capital cost of a 500-MW plant that burns coal with a 0.5-percent sulfur content and removes 70 percent of the sulfur is estimated to be $140/kilowatt (kW). The capital cost is $200/kW for a 200-MW plant that burns 4-percent sulfur coal and is required to remove 90 percent of SO_2 emissions.

Another promising technology for reducing SO_2 emissions is **sorbent injection**. This technology has the potential to reduce sulfur dioxide emissions by up to 70 percent. There are two types of sorbent injection: the furnace sorbent injection process and the low-temperature sorbent injection. Both processes should be available in the mid-1990s. The furnace sorbent injection process sprays a calcium-based sorbent material, such as limestone or calcium hydroxide, into the furnace. The heat decomposes the sorbent into lime which captures the SO_2 and forms calcium sulfate. The calcium sulfate and fly ash are separated. The low-temperature, or postcombustion, sorbent injection process introduces a calcium-based sorbent into the flue gas, but farther downstream from the combustion zone. Postcombustion sorbent injection is potentially cheaper than furnace sorbent injection and wet flue-gas scrubbing. Sorbent injection retrofits are estimated to cost from $48 to $99/kW, depending on the size and the difficulty of retrofitting the plant. In the United States, several commercial-scale utility projects are now demonstrating furnace sorbent injection.

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[33] *Environmental and Energy Study Conference Report*, op. cit., footnote 30.

[34] U.S. Congress, Office of Technology Assessment, op. cit., footnote 27.

[35] This section is drawn from the *National Acid Precipitation Assessment Program Report 25*, op. cit., footnote 28.

Currently, NO_x emissions are reduced by modifying the design or operating conditions of combustion equipment. Common techniques include lowering excess combustion air, recirculating the flue gas, and injecting steam or water into the firebox. Reducing excess air reduces the quantity of atmospheric nitrogen available for NO_x formation. Flue-gas recirculation and steam or water injection reduce flame temperature, which is an important factor in decreasing NO_x production. Some of these techniques may reduce energy efficiency because they lower combustion temperatures.

Low NO_x burners are standard features on almost all recently built utility boilers. According to the NAPAP report, low NO_x burners can reduce NO_x by up to 80 percent. The low-NO_x burner technology restricts airflow into the combustion chamber, which lowers combustion temperatures and NO_x formation. In the United States very few retrofits have been performed. Thus, costs are difficult to determine. NAPAP indicated that retrofit capital costs could range from $8 to $34/kW.

Other advanced technologies such as gas reburning and staged combustion could be commercially available in the United States by the mid-1990s. **Gas reburning** has been used in Japan as a retrofit to oil- and gas-fired plants. In this process, the primary fuel is burned in a secondary combustion zone, which destroys the NO_x produced in the primary combustion zone. Gas reburning has the potential to reduce NO_x emissions by 40 to 75 percent. Several commercial projects have demonstrated fuel reburning using natural gas and coal as the reburning fuel.

Another advanced technology is **selective catalytic reduction (SCR)**. The SCR process is the only commercial control technology that can reduce nitrogen oxides up to 90 percent. SCR is a flue-gas treatment process that reduces NO_x to molecular nitrogen and water by reacting ammonia with NO_x in the presence of a catalyst at temperatures between 300 and 400 degrees Celsius. The catalyst is the primary capital and operating cost component of this technology. SCR can be used in a wide variety of applications, including new and retrofit coal-, oil-, and gas-fired facilities.

Japan and Germany have considerable experience with SCR. U.S. experience with this technology is more recent but expanding. SCR has been used on several gas-fired combustion turbines in California and New Jersey, but has not been applied commercially on boilers that burn high-sulfur and high-alkaline ash content coals. Many boilers in the United States use these types of coal. Before SCR is widely used in this country, concerns about catalyst life, performance, and costs must be addressed.

Gasification

Gaseous fuels can be synthesized by combining coal with varying amounts of hydrogen and oxygen. Gasification technologies can be used to produce substitute natural gas (SNG); synthesis gas, which can be converted to liquid fuels or used to manufacture chemicals; and to generate electricity in gasification combined cycle systems.

In the 1970s, there was a great deal of interest in coal gasification because of concerns about the adequacy of natural gas supplies. More than 100 coal gasification projects were under consideration. Many have since been discontinued because of the changing energy picture. R&D continues on a few processes, such as, ash agglomerating, fluidized-bed process, British Gas/Lurgi gasifiers, and the Rheinbraun direct fludizied-bed hydrogasification process.[36]

The Gas Research Institute (GRI) is funding R&D on the direct methanation process, which converts hydrogen and carbon monoxide to methane and carbon dioxide. The process can be used to treat raw gas from a gasifier with little or no pretreatment. Direct methanation requires no steam. GRI hopes that direct methanation will improve the economics of converting coal to SNG.[37]

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[36] Oak Ridge National Laboratory, op. cit., footnote 4, p. 23.

Also, advances in acid gas removal could improve the economics of SNG production from coal. One of the critical elements in producing SNG is the removal of unwanted gases, such as CO2 and hydrogen sulfide, from the product stream. There are a number of commercial technologies that remove acid gases. However, only a limited R&D effort is directed at improving acid gas removal.[38]

Following the 1973-74 oil embargo, coal gasification became a valuable source of synthesis gas, which can be converted to chemicals and feedstocks. The CO_2 produced by the gasification process has a number of applications. For example, CO_2 is used in enhanced oil recovery operations, in the synthesis of urea (ammonia and fertilizers) and in the carbonation of beverages. Several plants use coal gasification to produce synthesis gas. A plant in Tennessee has been operating since 1983 and produces acetic anhydride, acetic acid, and methanol.[39]

Liquefaction

Liquid fuels can also be synthesized by chemically combining coal with varying amounts of hydrogen and oxygen. Coal liquefaction processes are generally categorized according to whether liquids are produced from the products of coal gasification (indirect processes) or by reacting hydrogen with solid coal (direct processes).

The first step in the indirect liquefaction process is to produce a synthesis gas consisting of carbon monoxide and hydrogen and smaller quantities of various other compounds by reacting coal with oxygen and steam in a gasifier. The liquid fuels are produced by cleaning the gas, adjusting the ratio of carbon monoxide to hydrogen in the gas, and pressurizing it in the presence of a catalyst. Depending on the catalyst, the principal product can be methanol or gasoline.

A number of large-scale gasifiers required for the indirect liquefaction process have been commercially proven. These include the Lurgi, Westinghouse, Texaco, and Shell processes. For the liquefaction component of the indirect process, the Fischer-Tropsch process has proven effective. This process has been demonstrated and proven effective in South Africa for converting synthesis gas to a variety of products, including propanes and butanes, diesel, fuel oil, and methane.

The direct liquefaction process produces a liquid hydrocarbon by reacting hydrogen directly with coal, rather than from a coal-derived synthesis gas. A variety of direct liquefaction processes have been developed. These include pyrolysis, solvent extraction, and catalytic liquefaction. Much attention has been given to a process that dissolves and hydrogenates the coal at high temperatures (800 to 850 degrees Fahrenheit) and pressure (1,500 to 3,000 pounds per square inch (psi)), with or without catalysts.[40]

In the United States, direct liquefaction is the most advanced of all the potential processes for producing liquid fuels from coal. Between 1972 and 1982, four pilot plants demonstrated the feasibility of direct liquefaction. One of the plants, the Wilsonville, Alabama Advanced Coal Liquefaction Research and Development facility, is still operating. Since 1983, improvements have been made in the quantity and quality of the liquid fuels produced (distillate fuel oil, kerosene, and gasoline). The increases in quantity and quality have improved the economics of liquefaction. According to ORNL, the current liquefaction process would be cost-effective at a crude oil price of $35 per barrel.[41]

Further advances are possible. DOE efforts have focused on improving catalysts that will allow efficient liquefaction using lower pressure and temperatures.

NON-FOSSIL FUEL ENERGY AND ADVANCED TECHNOLOGIES

Nuclear and renewable energy technologies provide less that 15 percent of our energy needs. However, many of the key decisions that will be considered are related to these technologies. Furthermore, they can contribute significantly to energy security and environmental quality, especially reduced CO_2 emissions.

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[37] Ibid.

[38] Ibid., p. 24.

[39] Ibid., pp. 24-25.

[40] Ibid., p. 33.

[41] Ibid., pp. 33-34.

The Nuclear Power Option

Nuclear power has come to an impasse for a variety of reasons. If there is to be a revival, many improvements are likely to be required to reactor technology and its management. In addition, progress on waste disposal must be sufficient to demonstrate convincingly that technology and sites for safe, permanent disposal will be available. Also, nuclear power is unlikely to be widely acceptable if it contributes, or has a significant potential to contribute, to the spread of nuclear weapons. Depending on how well these problems are met, nuclear power will either gradually wither away or resume its growth as a substantial contributor to our future energy needs.

Some observers doubt the viability of nuclear power. Construction costs are high, and overruns are common; catastrophic accidents are possible; and the problems and costs of waste disposal and plant decommissioning have not been resolved. In addition, foregoing nuclear power would enhance the moral leverage of nations seeking to stem the proliferation of nuclear weapons. The advantages to phasing out nuclear power, therefore, seem great.

Nevertheless, there are still strong national policy arguments for maintaining the option. An improved nuclear reactor may well be competitive with coal and much cheaper than oil or gas for electricity generation. Coal prices could also rise sharply with oil and gas if nuclear is not available as a competitor. Also, nuclear power is the only non-CO_2 option that can now be expanded rapidly.

The lack of nuclear plant orders since the mid-1970s raises questions of whether the industry will be able to respond adequately if new orders materialize. Specialized knowledge and facilities will be lost as the industry contracts. However, there is no "point of no return." Utilities are increasingly purchasing components for operating plants from foreign companies, and new orders could be supplied the same way, at least until the domestic industry rebuilds. Even entire reactors and major nuclear systems could be imported without great impact on the utility, its customers, or the national balance of payments. However, the situation is unlikely to get so extreme over the next few years. The major reactor vendors will probably be able to keep current, especially if it appears probable that a revival will occur, but many of the companies that produce minor but necessary components are dropping their certification. This suggests that the longer the hiatus before the next order, the slower the revival. Not only will design and manufacturing capabilities have to be rebuilt, but so will nuclear engineering departments at universities.

Nuclear Powerplant Technology[42]

The technology has largely, though not completely, matured. If a utility were to order another nuclear plant now, it could start construction with an essentially complete design, and the final product should not differ markedly from this design. In addition, the advanced designs now being readied by several of the reactor manufacturers are incorporating safety and reliability features that should go a long way to solving many of the past problems.

However, reliability and safety concerns have been so pernicious that even the most experienced utilities would not consider nuclear to be a viable option at present. The hostility, negative expectations, and encumbrances that were created by all the problems have left a legacy that will not be dissipated simply by showing that most of the problems have been alleviated.

If it is deemed desirable to preserve the nuclear option, there are two basic approaches to overcoming the problems discussed above. The present light water reactor (LWR) technology can be improved sufficiently that utilities would feel secure ordering a new plant. Standardized designs would be licensed after exhaustive safety analysis. Each applicant would use a preapproved design not subject to generic safety issues, so utilities would not face continual changes during construction. Only site-specific features would require custom design and licensing. Issuance of the operating permit would depend only on showing that the construction met standards. These designs would improve on current designs by simplifying operations and increasing safety. The advanced LWRs are a major step in this direction. This approach relies on the expertise that has been gained with several hundred LWRs in the world and the evolving maturity of a familiar technology.

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[42] This discussion is drawn from the OTA report, *Nuclear Power in an Age of Uncertainty*, OTE-E-216 (Washington, DC: U.S. Government Printing Office, February 1984).

Alternatively, an entirely different technology could be tried that should be so demonstrably safe that problems of changing regulation, public acceptance, and investor uncertainty should not be major factors. The **high-temperature gas reactor** (HTGR) and the **liquid metal reactor** (LMR) are alternative concepts that can incorporate passive safety features to the point where it is essentially impossible for an accident to occur that could result in off-site releases of radioactivity. However, both these concepts present uncertainties of operability and economics because of their unfamiliarity.

Both approaches (improved, familiar technology and radically different technology) have advantages and disadvantages. It should also be noted that it is entirely possible that neither will work, i.e., that the legacy of problems is so great that no reactor will prove acceptable.

No matter which approach is tried, standardization will be important. No nuclear plant will be cheap, and no utility is going to start construction without assurances that the plant will be both licensable and well designed to be operable and efficient. No reactor vendor or architect/engineer is likely to go to the trouble and expense of designing a plant and licensing the design unless it can apportion these costs among many sales. Standardization is the only way to meet these constraints. Customized plants can be just as safe and, under some conditions, just as economic, but for the next round of orders, standardization offers practical assurances of licensing and construction that are probably essential.

It is also noteworthy that any new plants in the United States are likely to be smaller than those from the early days of nuclear power. Due to uncertainties of future load growth and rate regulatory treatment, utilities are avoiding large plants of any type. All parties will want to limit their financial risk, and small plants cost much less though somewhat more per kilowatt of capacity. It should be much easier to demonstrate compliance with regulations and cost projections of a small plant since it would be more practical to build a full-scale demonstration model.

The ideal may well be modular units that can be largely factory manufactured and delivered rapidly as needed. Reactors are unlikely ever to be as simple to install as combustion turbines, but recent experience suggests (not unambiguously) that large plants are more subject to delays and cost escalation than small plants. Manufacturers are likely to find innovative ways to package small reactors that further reduce costs. Thus the economies of scale of large plants are probably not as great as has been thought in the industry and may be outweighed by other advantages of small units. Small, modular reactors are particularly appropriate for standardization as they will be assembled from components that can be serially manufactured. As the number of reactors ordered increases, costs should drop.

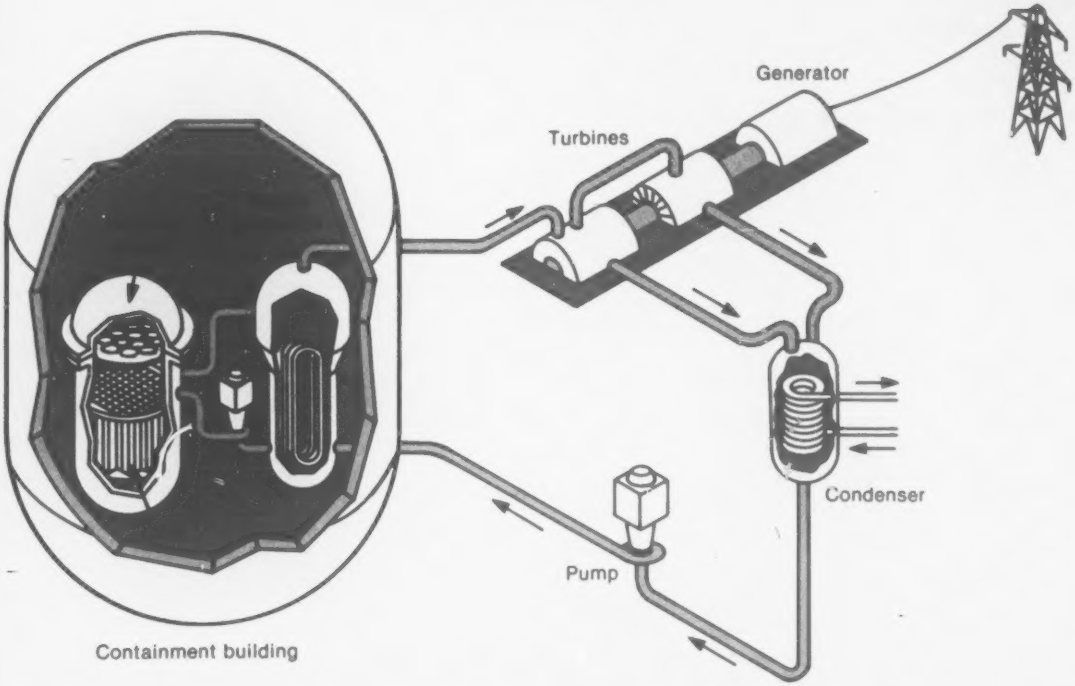
Advanced Light Water Reactor—Two different reactor designs have been developed for the LWR: the *pressurized water reactor* (PWR) and the *boiling water reactor* (BWR) (see figures 3-3 and 3-4). The PWR maintains its primary coolant under pressure so that it will not boil. The heat from the primary system is transferred to a secondary circuit through a steam generator, and the steam produced there is used to drive a turbine. In the United States, about two-thirds of the nuclear reactors are pressurized water reactors.

The BWR eliminates the secondary coolant circuit found in a PWR. In the BWR, the heat in the core boils the coolant directly, and the steam produced in the core drives the turbine. There is no need for a heat exchanger, such as a steam generator, or for two coolant loops. In addition, since more energy is carried in steam than in water, the BWR requires less circulation than the PWR.

LWRs have been operating in the United States for more than 25 years. They have had good safety records. There has never been an accident involving a major release of radioactivity to the environment. Their operating performance, while not as good as expected initially, has been comparable to that of coal-fired powerplants.

Improvements could be made to LWRs by redesigning the plants to address safety and operability concerns. Advanced LWR designs have been developed by Westinghouse Electric Corp. and General Electric Co. Efforts have been directed at reducing risks and improving reliability. For example, the new BWR design enhances natural circulation of the primary coolant, which increases the ability of the

Figure 3-3—Pressurized Water Reactor



SOURCE: U.S. Congress, Office of Technology Assessment, *Nuclear Power in an Age of Uncertainty*, OTA-E-216 (Washington, DC: U.S. Government Printing Office, February 1984), figure 20.

coolant to remove decay heat in the event the main circulation system fails. In the new PWR design, coolant piping has been reconfigured and the amount of water in the core has been increased to reduce the possibility that a pipe break could drain the primary coolant enough to uncover the core.

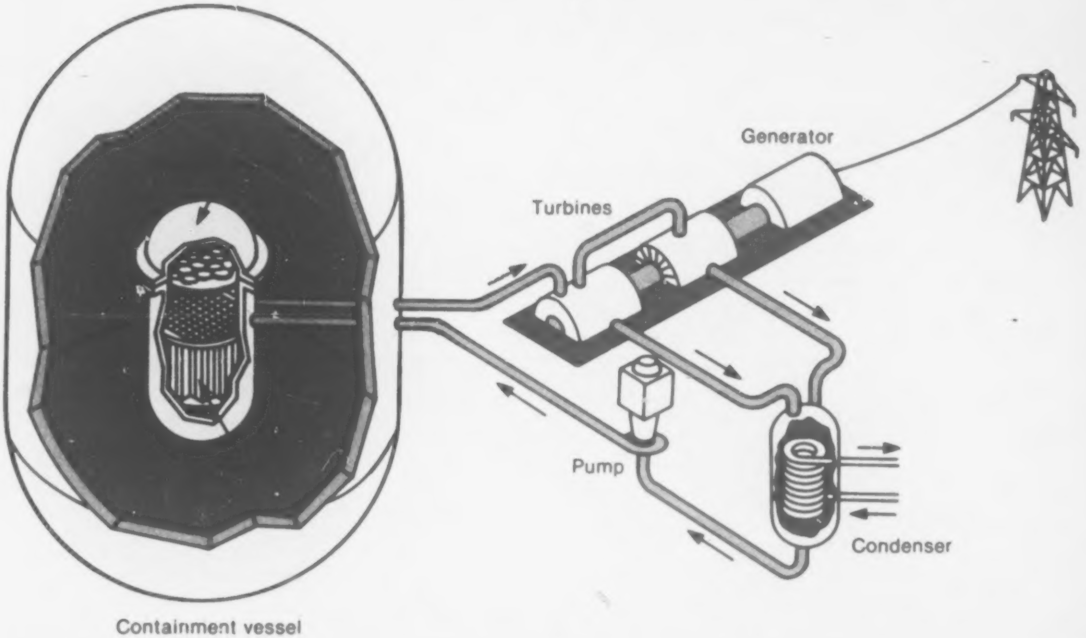
Inherently Safe Advanced Reactor Concepts—Incentives for developing a more forgiving reactor arise from several sources. LWR designs have evolved in a patchwork fashion, and there are still a number of unresolved safety and reliability issues. Also, the Three Mile Island accident heightened concerns about the susceptibility of LWRs to serious mishaps arising from human error. A more forgiving reactor design became desirable in terms of investment protection as well as public health and safety.

The *modular high-temperature gas-cooled reactor* (MHTGR) is an example of an effort to develop an inherently safe reactor. The MHTGR is cooled by helium and moderated by graphite, and the entire core is housed in a prestressed concrete reactor vessel. The reactor uses enriched uranium along with thorium, which is similar to nonfissionable uranium in that it can be transformed into useful fuel when it is irradiated. The fuel particles are coated with multiple layers of ceramic material and carbon. The ceramic coating can withstand extremely high temperatures (up to 1,600 degrees Celsius) without damage.

Because helium is used instead of water as a coolant, the MHTGR can operate at a higher temperature and a lower pressure than an LWR. This results in a higher thermal efficiency for electricity generation than can be achieved with other reactor designs. It also makes the MHTGR particularly suited for the cogeneration of electricity and process heat.

The gas-cooled reactor has several inherent safety characteristics that reduce its reliance on engineered devices for safe reactor operation. First the use of helium as a primary coolant offers some advantages. Because helium is noncorrosive in the operating

Figure 3-4—Boiling Water Reactor



SOURCE: U.S. Congress, Office of Technology Assessment, *Nuclear Power in an Age of Uncertainty*, OTA-E-216 (Washington, DC: U.S. Government Printing Office, February 1984), figure 20.

temperature range of the reactor, it causes little damage to components. Furthermore, it is transparent to neutrons and remains nonradioactive as it carries heat from the core. Also, the design of the fuel and core structure for the gas-cooled reactor has inherent safety features. The fuel can withstand very high temperatures, and the large thermal capacitance of the graphite in the core and support structures would slow the temperature rise even if the flow of coolant was interrupted. Operators would have a great deal of time to diagnose and correct a situation before the core is damaged. Even if all measures fail, heat transfer out of the core should always be high enough to prevent damage to the fuel pellets and resultant catastrophic release of radioactivity.

The high-temperature gas-cooled reactor was successfully demonstrated in 1967. The plant, Peach Bottom 1, operated at an average availability of 88 percent. A much larger plant that was to have been the prototype for commercial plants was built at Fort St. Vrain, Colorado. This reactor, now closed, suffered from many problems though the nuclear part worked well. These problems are partly responsible for a change in direction to smaller, modular gas reactors.

Preliminary conceptual design of a modular reactor has been completed. The simplification of plant design using passive features and factory fabrication should overcome the economic disadvantages of smaller size. Because of its modest size and passive safety features, the MHTGR technology is well suited to export markets. A number of countries have expressed interest in the MHTGR. They include the U.S.S.R., Italy, Israel, and China.

In addition to the MHTGR reactor, a small, passively safe liquid metal reactor (LMR) is being developed—the *power reactor inherently safe module* (PRISM). The PRISM technology uses liquid sodium to cool the reactor core. The reactor vessel is housed in an outer "guard" vessel. The purpose of the outer vessel is to catch any leaking sodium. There is a 5-inch gap between the two vessels, which is filled with argon to prevent the reaction of sodium with air. Both vessels are placed in an underground concrete silo. Air is allowed to circulate freely between the silo wall and the "guard" vessel to

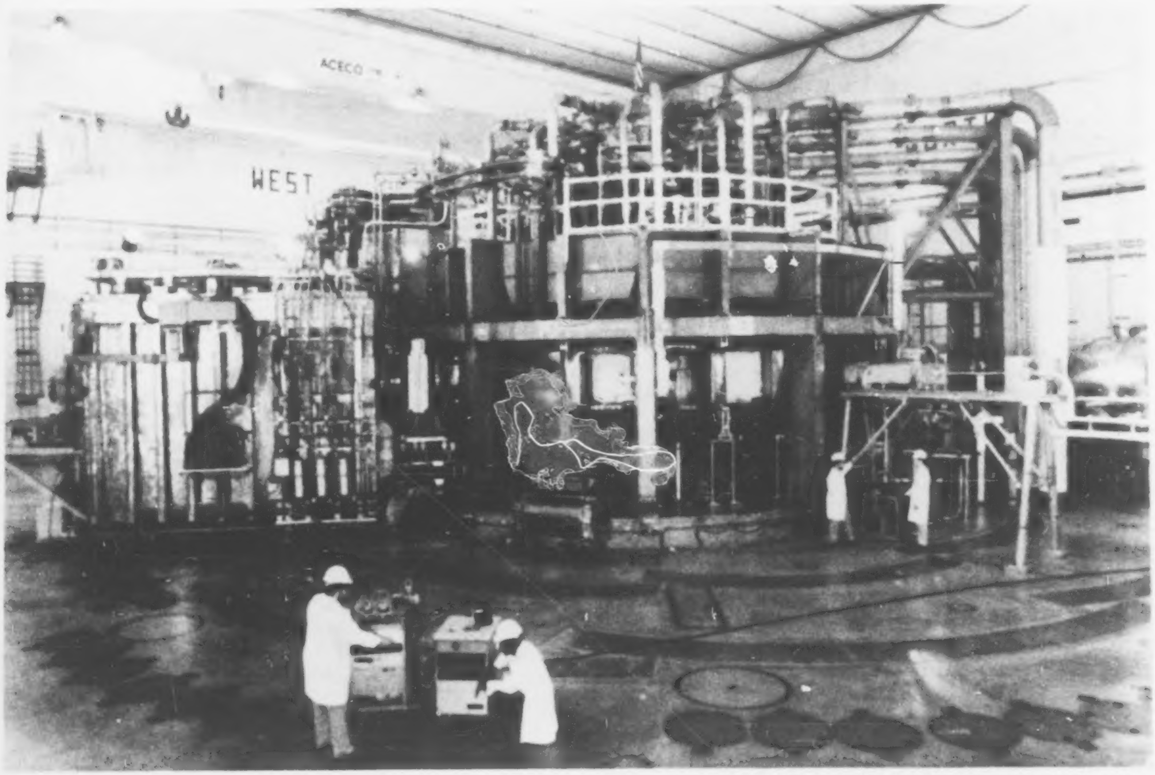


Photo credit: Princeton Plasma Physics Laboratory

The Tokamak Fusion Test Reactor at Princeton Plasma Physics Laboratory, where the first ever experiments on deuterium-tritium plasmas are scheduled to occur in 1993.

remove residual heat passively to the outside. DOE is funding PRISM research, and conceptual designs are expected to be completed in 1991.[43]

Resource Extension

The technologies for fuel reprocessing and breeding are well developed. Over the last three decades the United States has spent about $16 billion on breeder reactor technology. The **liquid metal sodium-cooled fast breeder reactor** (LMFBR) is the system of choice for breeding.[44]

The LMFBR is conceptually similar to the LMR. However, the LMFBR has a higher breeding ratio. The LMFBR can convert uranium-238 into fissile plutonium at a rate faster than its consumption of fissile fuel.

The reactor fuel rods contain a mixture of plutonium dioxide and depleted uranium dioxide. A blanket of rod containing depleted uranium dioxide surrounds the core. The initial loading could use either plutonium recovered from spent light water reactor fuel or enriched uranium. Subsequent loadings would use plutonium bred in the LMFBR.

The most serious risks from reprocessing are increased opportunities for the proliferation of weapons and the possibility of nuclear terrorism. Little economic justification exists now for reprocessing but, as the number of reactors grows, uranium prices will eventually rise. So will the value of the plutonium, leading to economic incentive to recover and recycle.

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[43] "New Interest in Passive Reactor Designs," *EPRI Journal*, vol. 14, No. 3, April/May 1989, pp. 10-12.

[44] Oak Ridge National Laboratory, op. cit., footnote 4, p. 58.

Fusion

Over the past 35 years, there has been great progress in nuclear fusion research, but there remain many scientific and technological issues that need resolution before fusion reactors can be designed and built. According to OTA, 30 years of additional R&D are required before a prototype commercial fusion reactor can be demonstrated. If successfully developed, fusion has the potential to provide society with an essentially unlimited source of electricity. It may also offer significant environmental and safety advantages over other energy technologies. Fusion technology is beyond the timeframe of this report, but it is one of only three long-term options. R&D must continue on fusion if the United States is to have the technology by the mid-21st century.

Nuclear fusion is the process by which the nuclei of two light atoms combine or fuse together. The total mass of the final products is slightly less than the total mass of the original nuclei, and the difference—less than 1 percent of the original mass—is released as energy.

Hydrogen, which is the lightest atom, is the easiest to use for fusion. Two of its three isotopes, deuterium and tritium, in combination work best in fusion reactions. When deuterium and tritium react, kinetic energy is released. This energy is converted to heat, which then can be used to make steam to drive turbines.

However, certain conditions must be met before hydrogen nuclei fuse together. The nuclei must be heated to about 100 million degrees Celsius. At these temperatures, matter exists as plasma, a state in which atoms are broken down into electrons and nuclei. Keeping a plasma hot enough for a long enough period of time, and effectively confining it are crucial for generating fusion power.

The behavior of plasmas, and the characteristics, advantages, and disadvantages of various confinement concepts need further study. At this stage, it is not known which confinement concept can form the basis of an attractive fusion reactor. The tokamak, which is a magnetic confinement concept, is the most developed, attaining plasma conditions closest to those required in a fusion reactor. Its principal confining magnetic field is generated by external magnets that run in toroidal direction. The tokamak also contains a poloidal magnetic field that is generated by electric currents running within the plasma.

Research on alternatives to the tokamak continues because it is not clear that the tokamak will result in the most attractive or acceptable fusion reactor. For an indepth discussion of fusion R&D, the reader is referred to the OTA report *Star Power: The U.S. and the International Quest for Fusion Energy.*

Future Electricity Supply Options

The U.S. electric power industry experienced tremendous change during the 1970s and 1980s, leading to considerable uncertainty. Because of this uncertainty, utilities now consider a broader range of options to accommodate future demand. In addition to its reliance on conventional technologies, utilities employ less capital-intensive and nontraditional options to ensure supply adequacy. These include load management and conservation programs, life extension of existing facilities, smaller-scale power production, and increased purchases from other utilities and nonutility generators. These options offer utilities more flexibility in responding to demand fluctuations.

Utilities are using demand management programs to reduce system peak demand and to defer the need for future generating capacity additions. Demand management programs include activities undertaken by a utility or customer to influence electricity use. Some utilities are just initiating demand management programs while others have been heavily involved for years and very dependent on these programs to meet system electricity needs. Demand management programs are discussed in chapter 2.

Life extension or plant improvement options are receiving more attention as a way of deferring the need for new capacity. Many of the older (30 or more years) plants have attractive unit sizes (100 MW or larger) and performance characteristics (heat rates close to 10,000 British thermal unit/kilowatt hour (Btu/kWh)). And, in many cases, plant improvement can also increase efficiency up to 5 to 10 percent and/or upgrade capacity. Refurbishments are underway at a number of utilities. For more detailed information about plant improvement opportunities, see OTA's assessment *New Electric Power Technologies: Problems and Prospects for the 1990s.*

Purchasing power from other utilities and nonutility generators is yet another option to ensure supply adequacy. The development of sophisticated communications equipment and control technologies and cost differentials have fostered an increasingly active market in bulk power transactions among utilities. Bulk power transfers constitute a significant share of total U.S. electricity sales. Canadian power imports are also increasing.

This section focuses on a number of new promising technologies for electric power generation. These include the intercooled steam injected gas turbines, combined cycle conversion, and fuel cells.

Advanced Turbines

Turbines fueled by oil or gas have provided electric power for five decades. They were used primarily to meet peak loads because of their relatively low efficiency. Recently, they have attracted renewed attention because of their low capital cost and improved fuel efficiency. New turbine technologies and advanced materials have allowed for hotter combustion temperatures. Many of the advances in design and high-temperature materials for turbines result from military R&D for improved jet engines.

The steam injected gas turbine (STIG) has far greater power and electrical efficiency than older designs, as discussed in the cogeneration section of chapter 2. The addition of intercooling to the STIG (ISTIG) should further increase power and efficiency improving their value for central power station applications. Part of the incoming compressed air used for combustion is passed through the turbine blades for cooling. This permits higher combustion temperatures. General Electric is conducting design work and indicates that this technology will be able to reach an average efficiency of 48.3 percent at an installed capital cost of $400/kW.[45]

Adding a steam turbine to a combustion turbine is another relatively new approach, called the combined cycle. A combined cycle powerplant is highly fuel efficient (up to 47 percent).[46] The steam turbine portion of a combined cycle plant can be added long after the combustion turbine has been in service, allowing greater planning flexibility. A key technological development allowing for widespread acceptance of combined cycle plants has been improving the reliability of the combustion turbines.

It may also be economically feasible to convert a combined cycle plant to run on gas derived from coal, as in an IGCC system. The turbine initially can be fired by natural gas, delaying construction of the coal gasifier until fuel prices and other economic conditions warrant. The IGCC is discussed in the coal section of this chapter.

Fuel Cells

Fuel cells produce electricity by an electrochemical reaction between hydrogen and oxygen, which, at least in theory, can produce electricity much more efficiently than current technology for burning fuel. The hydrogen can be supplied by a hydrocarbon fuel. A typical fuel-cell powerplant consists of three major components: fuel processor, fuel-cell power section, and power conditioner. The fuel processor extracts hydrogen from the fuel. The hydrogen is then fed into the fuel-cell power section. The fuel cells are joined in a series of stacks which form the powerplant. The electrical power that flows from the stacks is direct current (DC). With some voltage regulation, the DC power can be used if the load is capable of operating with DC. Otherwise a power conditioner is required to transform the DC into alternating current (AC). Neither combustion nor moving parts is required in the production of power. A single fuel cell produces about 1 volt.

There are several types of fuel cells being developed. They are categorized according to the type of electrolyte used in the conversion process. Fuel cells that use phosphoric-acid as the electrolyte are the most developed, but concerns about performance and costs persist. The phosphoric-acid fuel cell is likely to account for most of the fuel cells deployed in the 1990s. Other fuel cells employ alternative electrolytes such as molten carbonate and solid oxide. Molten carbonate and solid oxide fuel cells reform hydrocarbon fuels directly in the cell. These fuels cells, which operate at high temperatures, produce waste heat that can be used for cogeneration applications. The molten carbonate and solid oxide fuel cells are not expected to be deployed until the late 1990s at the earliest.

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[45] Robert H. Williams and Eric D. Larson, "Expanding Roles for Gas Turbines in Power Generation," reprinted from *Electricity—Efficient End-Use and New Generation Technologies, and Their Planning Implication* (no date), p. 531.

[46] "Utility Turbopower for the 1990s," *EPRI Journal*, April/May 1988, pp. 5-13.

Fuel cells are expected to produce electricity with modest environmental impacts relative to those of combustion technologies. Efficiency is estimated to be between 36 to 40 percent for smaller units and 40 to 44 percent for larger ones, and future technology may realize efficiency rates well over 50 percent. Another advantage is the short leadtime (2 to 5 years) required to build a fuel-cell powerplant. Because fuel cell systems are modular, they can be built at a factory and assembled at the site. Installation can be accomplished in many locations, including areas where both available space and water are limited. Other advantages include fuel flexibility and responsiveness to changes in demand.[47]

The installed capital costs of prototype fuel-cell powerplants are about $3,000/kWe. The fuel cell power section will account for about 40 percent of the costs. Operating and maintenance costs are estimated to range from 4.3 to 13.9 mills/kWh. Replacing cell stacks will account for the largest share of operation and maintenance costs. Fuel costs are expected to be about 27 to 33 mills/kWh.[48]

Magnetohydrodynamics

In magnetohydrodynamic (MHD) generators, a stream of very hot gas from a furnace (about 5,000 degrees Fahrenheit) flows through a magnetic field at high velocity. Because the gas is an electrical conductor, current is produced through electrodes mounted on the sides of the gas duct. Used in conjunction with conventional power technology, MHD might raise plant efficiency by 10 percent. However, many difficult technical problems remain unsolved, especially for coal-fired MHD systems. Perhaps the strongest argument for continuing a high level of R&D activity is the promise of being able to extract more useful energy from coal if concerns over CO_2 emissions prove accurate.

Storage[49]

Electricity storage is of enormous benefit to utilities. Storage reduces the amount of generating capacity that is required to meet peak loads and spinning and transmission reserves. Utility customers also can use storage devices to avoid the high price of electricity during peak periods.

Advanced batteries, compressed air energy storage (CAES), and pumped hydro are storage technologies that are well developed and could, under certain circumstances, be used in the 1990s.

Advanced Batteries—Batteries are more efficient and flexible than mechanical energy storage systems. In addition, they are modular and thus require short leadtimes to construct. Capacity can be added as needed and sited near the intended load. A battery's ability to react in a matter of seconds makes it valuable for optimizing a utility's operations.

Three types of utility-scale batteries are promising: advanced lead, zinc-chloride, and sodium sulfide (NaS) batteries. Lead batteries are widely used today, mostly in cars.

Lead-acid batteries consist of a negative lead electrode and a positive lead dioxide electrode immersed in an electrolyte of sulfuric acid. As the battery discharges, the electrodes are dissolved by the acid and replaced by lead sulfate, while the electrolyte becomes water. When the battery is recharged, lead is deposited back on the negative electrode, lead peroxide is deposited back on the positive electrode, and the concentration of acid in the electrolyte increases.

Over the years, research has continually improved lifetime cycles of the lead-acid battery. It is possible to buy a load-leveling lead-acid battery with a guaranteed lifetime of 1,500 cycles (about 6 years). Refinements could further improve the lifetime up to 3,000 to 4,000 cycles.

One of the disadvantages of lead-acid batteries is capital cost. Operation and maintenance costs are dependent on the durability of various battery components in a corrosive environment and how the battery is used. According to OTA, the largest component of operation and maintenance costs will most likely stem from the periodic replacement of battery stacks.

Zinc-chloride batteries have been under development since the early 1970s. During charging, zinc is removed from the zinc-chloride electrolyte and deposited onto the negative graphite electrode in the battery stack. Chlorine gas is formed at the positive electrode. The gas is pumped into the battery pump, where it reacts with water at 10 degrees Celsius to form chlorine hydrate, an easily manageable slush. During discharge, the chlorine hydrate is heated to extract the chlorine gas, which is pumped back into the stack, where it absorbs the zinc and releases the stored electrical energy. The zinc-chloride technology is complex and is sometimes described as being more like a chemical plant than a battery.

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[47] Oak Ridge National Laboratory, *Energy Technology R&D: What Could Make a Difference?* vol. 2, Part 1, "End-Use Technology," ORNL-65441/V2/P1, December 1989, p. 138.

[48] U.S. Congress, Office of Technology Assessment, op. cit., footnote 27.

[49] Unless otherwise noted, most of this section is based on the OTA report *New Electric Power Technologies: Problems and Prospects for the 1990s*, op. cit., footnote 27. For more information on this topic the reader is referred to this report.

Cost estimates for the zinc-chloride battery are about $500/kWe, less expensive than the lead-acid type because of the inexpensive materials that go into its manufacture. The operation and maintenance costs are uncertain. However, the expected longer lifetimes and less expensive replacement costs for the stacks and sumps could levelize replacement operation and maintenance costs in the 3- to 9-mills/kWh range.

A major safety concern is associated with the accidental release of chlorine. Because chlorine is stored in a solid form, sumps must be sufficiently insulated so that in the event of a refrigeration system malfunction the chlorine will stay frozen.

Interest in commercializing the NaS battery is strong, and funding has reached about $140 million annually.[50] The NaS battery system requires an operating temperature of 350 degrees Celsius. At this temperature, both the sodium and sulfur are liquid. During discharge, sodium is oxidized at one electrode and travels through the electrolyte where it is reduced at the second electrode to form sodium polysulfide. The major advantages of the NaS battery are its high overall efficiency (88 percent) and its high energy density compared with that for the lead-acid battery. One of the primary concerns over this technology is maintaining the high operating temperature during both charging and discharging. Fluctuations in temperature will result in electrolyte cracking.[51]

Compressed Air Energy Storage—A CAES plant is a central storage station where off-peak power is used to pressurize an underground storage cavern with air. The compressed air is later released to drive a gas turbine. The first U.S. CAES project was scheduled to begin commercial operation in March 1991. Alabama Electric Cooperative, Inc. owns the 110-MW plant.[52]

In a conventional plant, the turbine must power its own compressor, which leaves only about one-third of the turbine's power available to produce electricity. The compressed air from a CAES is used in a turbine which, freed from its compressor, can drive an electric generator up to three times as large. The gases discharged from the turbine pass through a "recuperator," where they discharge some of their heat to the incoming air from the cavern, increasing the overall efficiency of the plant. (See figure 3-5.)

Three types of caverns may be used to store air: salt reservoirs, hard rock reservoirs, or aquifers. The salt reservoirs are found in Louisiana and eastern Texas. Salt caverns are mined by pumping a water-based solution into the deposit and having it dissolve a cavern. Salt caverns are air tight.

Rock caverns are located throughout the United States. They are excavated with underground mining equipment. A compensation reservoir on the surface maintains a constant pressure in the cavern as the compressed air is injected and withdrawn. Aquifer reservoirs are naturally occurring geological formations, occurring in much of the Midwest, the Four-Corners region, eastern Pennsylvania, and New York. They consist of porous, permeable rock with dome-shaped, nonporous, impermeable cap rock overlying them. The force of the surrounding water confines the compressed air and maintains it at a constant pressure as it is injected and withdrawn from the rock.

Compared to batteries, CAES plants are in a more advanced stage of development and are likely to be less expensive than batteries on a dollar per kilowatt-hour basis. However, CAES plants require longer leadtimes to construct, probably from 4 to 6 years, depending on size.

Pumped Hydro—There are numerous pumped hydro plants in the United States. Some plants require a large, above-ground reservoir while others store water underground. Above-ground reservoirs have become difficult to site, and underground storage is only economical in very large units.

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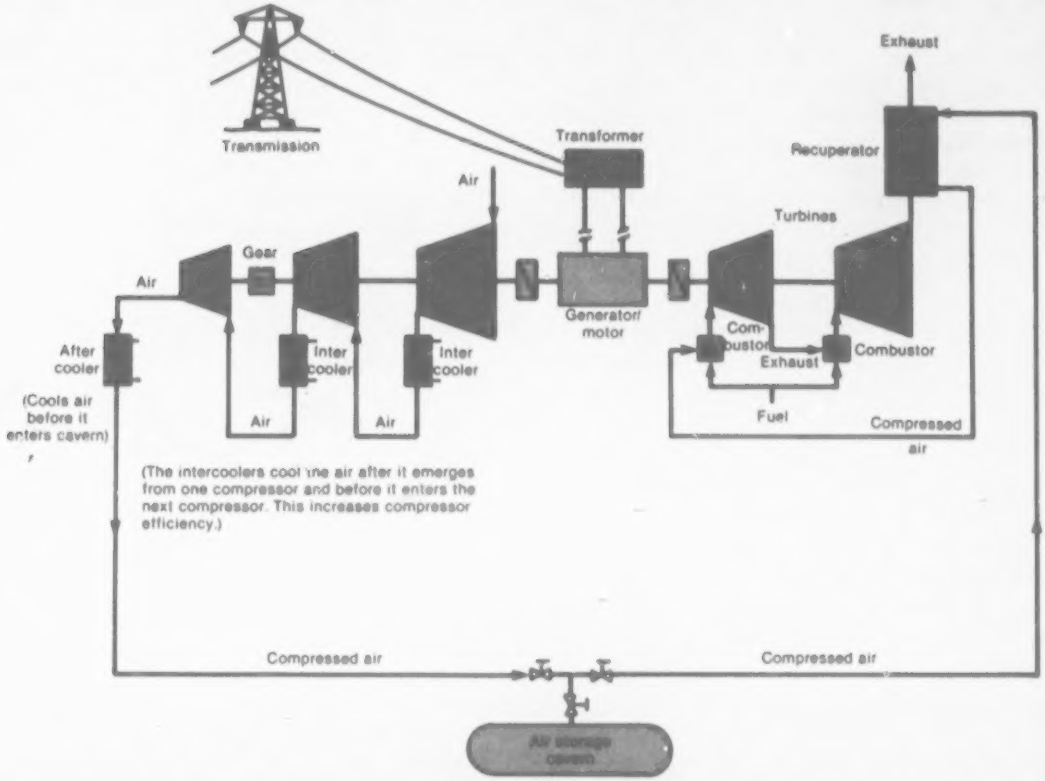
[50] Oak Ridge National Laboratory, "End-Use Technology," op. cit., footnote 47, p. 163.

[51] Ibid.

[52] "Compressed Air Used To Produce Economical Peak Power," *Power*, vol. 134, No. 6, June 1990, p. 77.

Figure 3-5—First Generation CAES Plant


Exhaust
Transmission
Transformer
Recuperator
Air
Turbines
Gear
Air
Generator/ motor
After cooler
Inter cooler
Inter cooler
Com-bustor
Exhaust
Combustor
(Cools air before it enters cavern)
Air
Air
Fuel
Compressed air
(The intercoolers cool the air after it emerges from one compressor and before it enters the next compressor. This increases compressor efficiency.)
Compressed air
Compressed air
Air storage cavern

A Compressed Air Energy Storage (CAES) plant is a modification of a conventional gas turbine cycle. Its principal components are combustion turbines, compressors, a generator/motor, and an underground storage cavern. The system stores energy by using electricity from the grid to run the compressor and charge the cavern with compressed air. This energy is discharged by releasing the compressed air to the combustion turbine where it is mixed with natural gas or oil and burned to produce the power which drives the generator. In a conventional gas turbine plant the turbine drives its own compressor simultaneously with the generator so that only a third of the turbine's total power is available to produce electricity. Thus, a CAES plant stores the energy in off-peak electricity to make a gas turbine three times as fuel efficient.

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SOURCE: U.S. Congress, Office of Technology Assessment, *New Electric Power Technologies: Problems and Prospects for the 1990s*, OTA-E-246 (Washington, DC: U.S. Government Printing Office, July 1985), figure 4-27.

A pumped storage plant recycles the water that flows through its turbine, sending it through a reversible turbine from a lower to an upper reservoir for reuse. Although pumped storage facilities use more energy for pumping than they generate for power, they assist in peak power production, when electricity is most costly to produce. Replenishing the upper reservoir occurs during off-peak hours using the utility's least costly resources.

Expanded use of pumped storage facilities could improve overall efficiency. Currently, U.S. pumped storage capacity is only 3 percent of the country's total capacity. Foreign studies suggest that increas-

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[33] Solar Energy Research Institute et al., *The Potential of Renewable Energy, an Interlaboratory White Paper*, prepared for the U.S. Department of Energy (Golden, CO: Solar Energy Research Institute, March 1990), p. A-3.

Photo credit: Casazza, Schultz & Associates, Inc.

A high-voltage transmission corridor.

ing the share to 20 percent might benefit the U.S. power grid.[53]

Other storage technologies are flywheels, and superconducting magnet energy storage. These technologies are not likely to be commercial before the year 2000.

Transmission and Distribution

Transmission and distribution lines carry electric energy from the powerplant to the user. Most transmission in the United States consists of overhead AC lines operated at 69 kilovolt (kV) or above. Distribution systems operate at lower voltages, typically under 35 kV, to transport smaller amounts of electricity relatively short distances.

Transmission systems are extraordinarily complex. They must be developed in concert with generating plants, but utilities are experiencing increasing difficulty in siting lines. Few important lines have been stopped, but that may not be true in the future. One of the major issues is the health effects of electric and magnetic fields, discussed later in this chapter. The technical options discussed here may help alleviate some of the concerns.

In recent years, long-distance transmission has increased significantly. Transmission capacity in some regions is already strained by the high usage. Improvements in transmission and distribution technologies can improve performance and reliability. Options for increasing transmission capability include improving control of reactive power and voltages on a network and increasing the thermal or voltage capacity of an individual existing line, improving control of power flows on a network, decreasing the response time of generators and transmission line switching, and adding new lines.

Developments that may have significant long-term effects on transfer capability are high-power semiconductors, advances in computer and data processing, and in the very long term, possibly even superconductivity. High-power semiconductors are now being used on high voltage direct current (HVDC) powerlines to convert AC power to HVDC and back again. The high-power semiconductors (thyristors) used in this application are expensive enough that HVDC powerlines are only practical in long lines or as interconnections between asynchronous systems. Lower cost and high-capacity semiconductors will make shorter DC lines economically practicable and allow multiterminal HVDC lines, instead of the two terminals now used. Because the conversion voltages at both ends of the line can be controlled, HVDC transmission allows complete control of network flow.

Advances in communication and data processing should improve reliability and economy. The current transmission and distribution system is largely mechanically controlled. The development of more flexible transmission controls and distribution automation will allow more efficient operation, but at the price of complexity.

Superconductors will have a number of possible applications in the utility industry. These include: 1) magnetic energy storage, 2) superconducting generators, and 3) transmission lines.

Electricity storage may be the most likely early use of superconductors. The concept is less developed than the storage technologies discussed earlier, but superconducting magnets could be more economical and easily sited. The difficulties of this application include cost, refrigeration, and the enormous magnetic stress on brittle ceramic superconductors.

Another possible application is superconducting generators. Preliminary designs and testing have been done using lower temperature metal superconductors. Even small reductions of losses can be important because of the high-power flow involved.

Superconducting transmission lines are another possible application, but not as attractive as they might first appear. Although superconducting cables would have no resistance, this would have to be balanced against cooling losses and the cost of the cable and burial. HVDC circuits would benefit much more from superconducting lines. The cost of AC/DC conversion equipment will limit the use of superconducting lines until the price of high-power semiconductors declines. For more information about superconductivity, please see the OTA report *High-Temperature Superconductivity in Perspective*.

Hydrogen

Many technologies such as nuclear power and emerging options such as photovoltaics and wind are most suitable for the production of electricity. Insofar as the electricity can be loaded onto the power network and delivered to customers, that is the most efficient method. However, electricity has some significant disadvantages as an energy carrier. At present it cannot be stored economically, and it is expensive to transport long distances although, as discussed above, new technologies may change these conclusions.

A potential alternative is to produce hydrogen, most probably by electrolyzing water, and delivering it via pipelines, much like natural gas. Hydrogen provides inherent storage, as does natural gas; it is less expensive to ship long distances than electricity; and it can be consumed almost as cleanly—the combustion product being water vapor (a small amount of NO_x may also result).

However, hydrogen also involves several disadvantages. Costs would be high unless the electricity is extremely inexpensive (in which case the losses of long-distance transmission and storage of electricity would not be very important). Losses in the electrolysis process and in compressing and delivering the hydrogen would be substantial. Pipelines built for natural gas could be unsuitable because hydrogen can embrittle steel pipes, shortening their lifetimes, and because the energy density is lower than natural gas, limiting the amount that can be delivered. Thus new and expensive pipelines could be required.

The easiest displacement would be of natural gas, but demand for gas is greatest for heating in the winter, when most renewable energy technologies have relatively low output. Thus, annual storage would be required if hydrogen were to become a significant part of the energy system. Hydrogen would be more valuable as a replacement for gasoline, but storage in small quantities in automobiles would be almost as difficult as storing electricity in batteries.

Hydrogen may play an important role eventually because of its natural partnership with intermittent solar technologies, but first the cost of those technologies must drop to very competitive levels. Lowering the costs of producing and storing hydrogen is the focus of DOE R&D efforts. Much R&D

effort is still needed to bring hydrogen concepts to the demonstration stage.

Renewable Energy Technologies

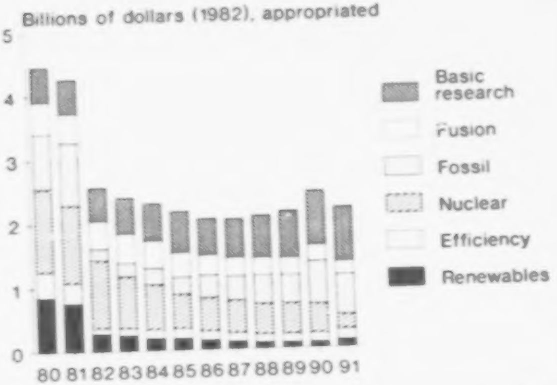
Renewable energy sources can supply space and process heat as well as electrical power. Some sources can be converted to feedstocks, for producing chemicals, or to fuel, for transportation. In general, the resource bases are inexhaustible and widely but irregularly distributed in both space and time, making storage very important. And, although the potential of each resource seems enormous, only a small amount of the resource is economically recoverable at present. As a group, renewable energy technologies are relatively clean and provide needed protection against a disruption in oil supplies. New energy technologies will enhance U.S. competitiveness and help reduce the trade deficit.

Continued R&D are needed to improve the efficiencies of promising renewable technologies, to reduce the risk of new technologies, and to help integrate renewables into existing energy systems. Yet, Federal funding for renewable R&D has declined over the last decade (see figure 3-6). Several recent studies have suggested that for a comparatively small increase in investment, the Federal Government could significantly hasten the development and deployment of renewable technologies. The Solar Energy Research Institute (SERI) and ORNL have concluded that the Federal budget for renewables R&D was only about half of what could be technologically justified.[54]

Hydroelectricity

Hydroelectric facilities use the kinetic energy in flowing water to generate electricity. Most hydropower facilities capture and store water via dams and reservoirs. Others operate in a run-of-river mode whereby water flow is not altered. Hydropower-generating capacity is affected by the volume flow of water and the difference in elevation of the water as it passes through the plant.

Figure 3-6—DOE Energy R&D Budget: 1980-1991 Selected Budget Lines



SOURCE: Congressional Research Service, *Energy Conservation: Technical Efficiency and Program Effectiveness*, IB85130, Updated Apr. 2, 1991, table 2.

In 1989, hydroelectric power contributed about 2.7 quads to total U.S. energy supplies.[55] Hydropower represents about 12 percent of installed electric generating capacity. Although the overall capacity of hydropower has doubled since 1960, the growth rate has slowed. The 88 gigawatts (GW) of present capacity include 64 GW of conventional hydro, 17 GW of pumped hydro, and 7 GW of small-scale (30 MW or less) hydro.[56]

According to SERI, only about half of the Nation's hydropower capability has been developed.[57] As of January 1, 1988, the United States has 76.1 GW of conventional hydropower and 19.1 GW of pumped storage capability still untapped. Of this amount, DOE estimates that for conventional hydropower it is economical to develop only 30 percent, or 22 GW, given current economic and regulatory constraints. By the year 2030, a net increase of 8-GW conventional and 5-GW pumped storage is projected, a growth of less than 0.5 percent per year.[58]

Hydropower is an attractive energy source because it is clean, it takes advantage of a large domestic resource base, and it responds quickly to utility load swings. Its availability (95 percent on average) is greater than that of thermal generating plants. Hydropower facilities are characterized by low annual operating costs, long service lives, and low emissions of pollutants. Hydropower facilities can also aid flood control and provide recreation.

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[54] U.S. Congress, Office of Technology Assessment, *Changing By Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991), p. 105.

[55] U.S. Energy Information Administration, op. cit., footnote 1, p. 9.

[56] Solar Energy Research Institute, op. cit., footnote 53, p. A-1.

[57] Ibid., p. A-3.

[58] Ibid., pp. A-3, A-4.

On the other hand, hydropower entails high initial capital costs, potentially serious environmental issues (e.g., aquatic life considerations and the loss of farmlands, wetlands, and scenic areas), dam safety concerns, and keen competition by other interests for use of the water base.

Technical Opportunities—Several areas of research promise to improve the economics of hydropower development and reduce its environmental drawbacks. For example, research on **hydroturbines** has resulted in technologies that may prove quite beneficial to hydropower development. A variable-speed, constant-frequency generator has been designed to alter the turbine speed in response to changes in the hydraulic head, allowing the turbine to operate at maximum efficiency.

New **ultralow-head turbines**, designed for use at sites with elevation differentials of less than 10 feet, could provide nearly 4,000 MW of additional capacity.[59]

Large-scale deployment of **free-flow turbines** for use in flowing rivers could help develop an additional 12.5 GW of capacity.[60] Use of such turbines would entail very little civil work, no impoundment of water, little disruption of flow, and no costly upgrade of dam structures.

The development of **cross-flow turbines** that optimize air injection and suction head in the draft tube and the design of replacement turbine runners with improved efficiency and air ingestion capabilities offer additional savings.

Further research is needed to identify and mitigate the environmental impacts of hydropower. Of particular interest are technologies to: 1) allow fish migrating downstream to bypass dams (upstream bypasses are reliable technologies), 2) specify insteam flow requirement for aquatic life, and 3) quantify the cumulative impacts of multiple-site development of a river basin.

Biomass[61]

Biomass already is a significant source of renewable energy. It is the only nonfossil liquid fuel for transportation applications. The industrial sector uses 2 quads of energy from biomass, almost all of it in the pulp, paper and lumber industries. Many of these industries use biomass in the cogeneration of heat and electricity. Furniture manufacturers and food processors are other significant users. The residential sector uses nearly 1 quad of firewood, mostly for space heating and cooking.[62]

Biomass Resources—The energy potential of biomass is enormous. DOE estimates a total energy potential of at least 55 quads in 2000, under certain conditions. Present capacity, excluding cultivated energy crops and wood and grain not used for biomass, is estimated to be 14 quads.[63]

Energy Crops—hardwood trees and herbaceous crops dedicated as energy resources—are the greatest potential source of biomass. The goal of providing a year-round, abundant supply of biomass is being supported by genetic engineering efforts and breeding research to increase yields and reduce costs of plants such as corn, sorghum, "energy" cane, and short-rotation hardwoods. DOE reports that during the next 25 years, average annual crop yields are expected to be 5 to 11 dry tons per acre. At 9 dry tons per acre, the use of 192 million acres of potential cropland could generate a gross biomass energy capacity of 26 quads. It is not known at this time how many acres could be devoted to energy crop production without having a major impact on other crops and forest production. Currently, about 900 million acres are classified as cropland or commercial forestland. Of that total, about 10 percent is withheld from production to either reduce crop productivity or for soil conservation purposes. An average of 328 million acres are planted annually.[64]

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[59] Oak Ridge National Laboratory, op. cit., footnote 4, p. 80.

[60] Ibid.

[61] Biomass refers to materials from biological sources that can be converted to fuel or feedstock: wood and wood wastes, residues from processing food and wood products, agricultural wastes, sewage and municipal solid wastes, aquatic plants and algae, and "energy crops" grown specifically to provide fuel or feedstock.

[62] Solar Energy Research Institute, op. cit., footnote 53, p. B-8.

[63] Ibid., p. B-17.

[64] Ibid., pp. B-5, 6.

Other sources of biomass are described below:

- *Conventional wood resources*, includes wood not used by the forest products industry in the thinning out of commercial forests. SERI estimates that conventional wood resources, if managed properly, could supply 6.5 quads of energy annually.[65]
- *Agricultural and forestry wastes* include primary and secondary residues. Primary residues are the stalks, limbs, bark, and leaves left on the land after harvesting. Expensive to collect, they are often left to enrich the soil. Secondary wastes emanate from processing (e.g., rice hulls, black liquor from pulping) and can often be used as fuel at little or no cost.
- *Agricultural oil seed crops* that produce vegetable oil offer an interesting but not yet commercial source of energy. Soybeans, which dominate this market, produce oil that is almost totally usable as fuel, yet soybean products are valued more highly for other uses. Rapeseed oil is a promising energy source.
- Certain *aquatic energy crops* produce oil that with upgrading could substitute for jet and diesel fuel. These plants include microalgae and macroalgae (e.g., kelp, cattails, water hyacinths, and spartina).

Biomass offers many environmental benefits. Carbon dioxide produced during combustion is balanced by reabsorption by the growing plants. Emissions of SO_x and other air pollutants are negligible or at least as easily controlled as those from fossil fuels.

Although abundant, biomass resources are thinly dispersed. Collecting and transporting biomass to conversion centers can be costly, considering its relatively low ratio of energy content to weight. If biomass is to become a major source of economical energy, additional crops will have to be grown that are more productive, less costly, and sited closer to conversion centers. Gearing up energy crop production will entail greater land and water use, with various impacts according to locale. Recent advances in biotechnology can improve plant productivity and develop new plants. For example, productivity can now be increased 5 to 10 times over the natural growth rate of trees.[66] However, the increase in biotechnology and genetic engineering efforts will have to satisfy concerns of public and environmental safety.

Converting Biomass to Energy—Biomass can be used directly as fuel or converted to other forms for use as fuel or feedstock. Ultimately, biomass will be more useful if converted to gaseous or liquid fuels, but the conversion process can cost as much as the collection of biomass and feedstock production.

Thermal Use of Biomass—The principal energy use of biomass is the production of heat, via direct combustion in air, for use in process heating, space heating, and cogeneration systems. About 64 percent of this energy is used by the lumber, pulp, and paper industries. Homeowners and commercial entities use the rest.

Electricity is produced primarily through the direct combustion of wood, wood wastes, and wood byproducts. Most users of biomass for power generation are nonutility generators (NUGs) that have ready access to wastes or byproducts at little or no cost. Many utilities, however, purchase power from cogenerators who use biomass as fuel. In 1989, biomass-fueled capacity accounted for about 20 percent of total NUG capacity (40,267 MW). Biomass capacity included agricultural waste, municipal solid waste, and wood.[67] Utilities now operate wood-fired powerplants in California, Maine, Michigan, Oregon, Vermont, Washington, and Wisconsin. About 5,200 MW of total utility capacity is wood-fired.[68]

The use of biomass by utilities is usually uneconomical and impractical. Biomass has a lower energy content than coal, and delivery costs are higher because of the dispersed nature of the resource. Generally, biomass must be procured within a 50-mile radius of the powerplant to be economical. EPRI estimates that the costs of producing electricity from a wood-fired plant is 11 cents/kWh compared to 7 cents/kWh for coal-fired plants.[69]

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[65] Ibid., B-5.

[66] Oak Ridge National Laboratory, op. cit., footnote 4, p. 84.

[67] Edison Electric Institute, *1989 Capacity and Generation of Non-Utility Sources of Energy*, April 1991, p. 9.

[68] Electric Power Research Institute, *Technical Brief*, "Wood—America's Renewable Fuel," RP2612-12, 1990.

[69] Ibid.

Gasification of Biomass—The production of methane (essentially natural gas) from biomass for supply to a natural gas system is accomplished by biological anaerobic digestion. Anaerobic digestion is particularly well-suited for very wet feedstocks and has been used commercially when biomass costs are low enough. Given a feedstock cost of $2.00/MBtu, methane can be produced for $4.50/MBtu, a cost not yet competitive with conventional natural gas unless other factors such as disposal costs are considered.[70]

Methane production from landfills, sewage treatment, and farm wastes will continue to increase but will be important only for specific locales. Biomass can also be converted by partial oxidation to syngas, which can be used as a fuel or as a feedstock for methanol production.

Production of Biofuels[71]—A variety of liquid fuels and blending components can be produced from biomass for use primarily in transportation. These biofuels include alcohol fuels (ethanol and methanol), as well as synthetic gasoline, jet, and diesel fuel.

Each year nearly 1 billion gallons of ethanol are added to U.S. gasoline stocks to create gasohol, a 90-percent gasoline/10-percent ethanol blend. The use of ethanol has gained support because of its potential contribution to the U.S. agricultural economy. The Federal Government and about one-third of the States subsidize ethanol use by partly exempting gasohol from gasoline taxes. Without these subsidies, ethanol would not be competitive with gasoline. OTA estimates that the full cost of producing ethanol ranges from $0.85 to $1.50/gallon, compared to wholesale gasoline prices of about $0.55/gallon.

Corn is the least expensive agricultural feedstock for ethanol production, especially when the byproduct of the production process can be sold. Wood and plant wastes are less expensive feedstocks, but the costs of available conversion processes are higher so that the net cost of producing ethanol from wood and plant wastes is more expensive than ethanol from corn. SERI is working on improving wood-to-ethanol processes and indicates that economic competitiveness can be reached by the year 2000.

Methanol can also be made from wood and other biomass materials, but the costs of production are uncertain. The National Research Council estimated that the crude oil equivalent price of methanol produced from wood, using demonstrated (not yet commercial) technology, is over $70/barrel. For biomass-based methanol to be competitive with coal-based methanol, improvements are needed in conversion technology and all aspects of growing and harvesting of biomass feedstocks. SERI expects the wood-to-methanol process to be ready for demonstration on a commercial scale by 2000 at the current R&D pace.

The production of diesel and jet fuel from microalgae is not as promising for the near term. Organisms with high growth rates that produce high oil content must first be developed. In addition, demonstration ponds must be built and operated on a large scale to make this process economical.

Converting biomass to synthetic hydrocarbon fuels through pyrolysis (thermal decomposition in the absence of air) of the biomass and catalytic upgrading of the biocrude to gasoline has been demonstrated in pilot plants but not developed for commercial use. Research results suggest a current cost estimate of the pyrolysis process to be $1.60/gallon for gasoline. A target of 85 cents/gallon is expected by 2005 if improvements are made in catalytic conversion and if feedstock costs are $2.00/MBtu.[72]

Commercial production of synthetic gasoline from biomass depends on improvements in the efficiency of the fast pyrolysis process. Specific needs include an increase in the yield and quality of the hydrocarbons produced. SERI expects that by 2020, fast pyrolysis technology should be commercially feasible at current levels of R&D.[73]

Geothermal Energy

Resources of natural heat below the Earth's surface can be used directly for space and process heat or converted to electricity. Although the actual resource is enormous—potentially 10 million quads[74] in the United States alone—the amount that can be recovered economically is small. Nevertheless, using available technology, about 23,000 MW of capacity from geothermal resources could be tapped over the next 30 years, according to the U.S. Geological Survey.[75] In 1989, the U.S. geothermal industry produced 2.8 billion kWh.[76] Modest technical advances could dramatically increase the use of this resource.

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[70] Solar Energy Research Institute, op. cit., footnote 53, p. B-7.

[71] For a more indepth discussion of alternative fuels, see the OTA report *Replacing Gasoline—Alternative Fuels for Light-Duty Vehicles*, OTA-E-364 (Washington, DC: U.S. Government Printing Office, September 1990).

[72] Solar Energy Research Institute, op. cit., footnote 53, p. B-7.

[73] Ibid., p. B-16.

Geothermal resources take several forms: steam, hot water, volcanic magma, hot dry rock, and geopressured brines. Except for brines located along the Gulf Coast, most of these resources underlie the western third of the country.

The Resource Base—The geothermal resource base includes usable heat contained within the Earth to a depth of about 3,000 feet.[77] Only 3.8 percent of this resource comes from *hydrothermal* reservoirs, naturally occurring hot water or steam at temperatures of 90 degree C. or more to a depth of 900 feet.[78]

Only a small portion of the hydrothermal resource is composed of the very hot (150 degree Celsius and more) vapor-dominated reservoirs used to generate electricity. Two-thirds of identified hydrothermal resources are in the moderate range of 70 to 121 degrees Celsius.[79] These resources and those that are of lower temperature show promise of recovery using available improved hydrothermal technologies.

The largest part of the geothermal resource base is found in: 1) magma, accessible regions of molten rock at temperatures of 850 degrees Celsius and higher; and 2) hot dry rock (HDR)—deep, hot regions of rock that can potentially be fractured by fluid pressure to create manmade reservoirs. No commercial recovery of either resource yet occurs. Likewise, energy from the geopressured-geothermal resource—zones of hot brine containing dissolved methane—that occurs mainly along the Gulf Coast has yet to be recovered.

Converting Geothermal Energy—Converting geothermal resources to energy entails bringing the resource to the Earth's surface via a production well and then converting geothermal energy to useful energy.

The technology for converting hydrothermal resources is well established. Dry natural steam can be converted to electric power by conventional turbine generators. Flash and binary cycle conversion technologies must be used to convert other geothermal resources. Flash steam technology is used with high-temperature liquids (less than 200 degrees Celsius) to produce steam to drive a turbine-generator. Binary cycle systems use the heat of a geothermal liquid to vaporize a second, working fluid. These systems are used when liquids are not hot enough (below 200 degrees Celsius) for flash steam approaches.

Although there has been little commercial experience with this technology, the dual-flash system is expected to be more efficient than the single-flash system now in extensive use. Dual-flash units are projected to be about 40 to 50 MWe in size by 1995.[80]

The binary cycle system is more complicated and costly because it uses a secondary working fluid, thus entailing special turbines and heat exchangers. Binary systems have an advantage in that the working fluid can have thermodynamic characteristics superior to steam, resulting in a more efficient cycle. Moreover, binary cycles operate efficiently at a wide range of plant sizes.

These same conversion systems used for hydrothermal resources can be adapted for recovering energy from geopressured zones, hot dry rock, and magma. Geopressured-geothermal resources can produce electricity at projected power costs of 7.5 to 16 cents/kWh, not counting the value of the natural gas byproduct.[81]

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[74] Office of Technology Assessment, op. cit., footnote 27, p. 96.

[75] Solar Energy Research Institute, op. cit., footnote 53, p. C-1.

[76] U.S. Energy Information Administration, op. cit., footnote 1, pp. 201-239.

[77] Ibid.

[78] Office of Technology Assessment, op. cit., footnote 27, p. 96.

[79] Ibid.

[80] Ibid., p. 98.

[81] Solar Energy Research Institute, op. cit., footnote 53, p. C-3.

Hot dry rock technologies offer great promise for commercially developing the large geothermal resource potential. The rock is fractured to create reservoirs into which water is pumped. Once heated, the water is brought back to the surface, where its heat can be used directly or converted to electricity. With the needed technology developed, this method is projected to generate power at 5 cents/kWh.[82]

The heat from magma is recovered by pumping water into the subsurface to extract heat. Field experiments to confirm drilling techniques, reservoir dynamics, and other parameters are needed before this technology can become commercial. Magma energy costs are estimated to be 4.5 to 8 cents/kWh.[83]

The costs of identifying and developing geothermal resources are high. Improved technology for resource exploration and reservoir confirmation could reduce costs as much as 25 to 40 percent for advanced concepts.[84] Moreover, predictions of reservoir performance must be enhanced.

Substantial cost reductions could also be made in drilling, completing, and operating geothermal wells. Accelerated research is needed on high-temperature equipment and corrosion-resistant materials. Savings of 15 to 20 percent for hydrothermal technology and 25 to 40 percent for advanced concepts could result. However, environmental issues, such as wildlife management and scenic considerations could restrict the development of some geothermal sites. SERI points out that the "not-in-my-backyard" syndrome is just as true for geothermal projects as it is for other energy facilities.[85]

Solar Thermal Electricity

Solar thermal electric plants use mirrors or lenses to concentrate sunlight, heating a fluid which is then used to produce electricity. Solar thermal systems operating with storage or with another fuel system offer significant potential for meeting peak or intermediate utility needs. Solar thermal electric plants produce 0.01 quad per year.[86]

Much progress has been made in the technology in the last decade. Several different solar thermal systems can produce electricity for about 12 to 15 cents/kWh. The DOE program goal is to produce electricity for 5 cents/kWh.[87]

Three technologies could be deployed competitively in the next 20 years: central receivers; and two distributed, or modular concepts, parabolic troughs and parabolic dishes.

Distributed systems have been more successful than central receivers. Since each unit is independent, it is easier to install. Each central receiver, however, must be designed for a specific number of heliostats (the concentrators). Heliostats must be individually focused on the central receiver and must follow a unique tracking system. However, it is not yet clear which concept will be superior in the long term.

Central Receivers—The central receiver is a fixed receiver mounted on a tower. At its base a large field of mirrors, known as heliostats, tracks the sun, reflecting solar energy onto the receiver. The mirrors must move both vertically and horizontally on a precisely determined path. Liquid or air inside the receiver transports the thermal energy to a steam-driven turbine for generating electricity. In the 1970s, several solar thermal electric plants were built, including the 10-MW Solar One Plant located in Dagett, California. The 30-MW Phoebus project in Jordan is the major central receiver project today.[88]

The most dramatic advances for central receivers have been in heliostat design and in the fluids used in the receiver. The most promise is seen in replacing the glass and metal mirrors in heliostats with stretched membranes of aluminum or steel sheets that are silvered on one face and curved to reflect solar energy at the right angle. Stressed membranes are about 20 percent of the weight of glass/metal

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[82] Ibid.

[83] Ibid.

[84] Ibid., p. C-5.

[85] Ibid.

[86] Ibid, p. E-3.

[87] Oak Ridge National Laboratory, op. cit., footnote 4, p. 105.

[88] Carl J. Weinberg and Robert H. Williams, "Energy From the Sun," *Scientific American*, March 1990, vol. 263, No. 3, p. 149.

Photo credit: Southern California Edison Co

The Solar One powerplant.

mirrors, which reduces the cost of the heliostat as well as the foundation and control system.

Research is also focused on replacing the steam/water in central receivers with molten nitrate salt. Molten salt can be maintained at lower pressures than steam (reducing pipe costs), and it stores heat well (reducing the need for heat exchangers or secondary systems). Storing several hours' worth of full power would allow complete load following in the summer when air conditioning peaks in the late afternoon.

Recent utility studies project annual central receiver system efficiencies of 14 to 15 percent, with costs of 8 to 12 cents/kWh for a next-generation plant using advanced receiver and heliostat technologies.[89]

Parabolic Dishes—A parabolic dish is a dish-shaped collector with a receiver mounted at its focal point near the center. Each module includes a two-axis tracking device. Several dishes are usually arrayed on a field, forming a distributed system. The concentrated heat may be used directly by a heat engine placed at the focal point, or may be transported by a fluid or air for remote use. Some designs use an array of mirrors, like a minicentral receiver.

New materials are being sought to replace traditional reflecting surfaces on the dishes. Of most interest is a stretched membrane of polymer. Other materials include large metal mirrors, mirrors incorporating structural support, and Fresnel lenses.

The most efficient system tested incorporates a free-piston Stirling engine at the focal point. About 30 percent of insolation can be converted to electricity by such a system, which is higher than any other solar electric technology.[90] The Stirling engine could be very reliable because of its mechanical simplicity, but it will need further development to improve its efficiency and cost.

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[89] Solar Energy Research Institute, op. cit., footnote 53, p. E-1.

Power costs from a system of stretched membrane dishes and a Stirling engine are projected to be 5 cents/kWh when commercially available.[91]

Parabolic Solar Troughs—Collectively, parabolic solar trough systems account for more than 90 percent of the world's solar electric capacity. A parabolic trough tracks the Sun vertically, which is simpler than the vertical and horizontal tracking required from heliostats and parabolic dishes. The trough concentrates sunlight onto a tube filled with fluid, usually very hot oil, at its focal line. The fluid circulates between troughs, finally transferring its heat through a heat exchanger to water or steam destined for a turbine generator.

Standing alone, solar troughs are best used for industrial applications. For electric power generation, supplemental gas-fired superheaters are used to create steam hot enough to drive a turbine.

From 1984 to 1988 several commercial solar trough plants, totaling 275 MWe, were built by the LUZ Corp. in California. LUZ is presently constructing 80 MWe of capacity, and is planning for 300-MWe additional capacity by 1994. These parabolic trough electric plants operate in the hybrid mode, using natural gas. Improvements in engineering, manufacturing, and construction techniques have reduced electric costs from 23 cents/kWh in early plants[92] to 8 cents/kWh in 1990. These are average costs, including the contribution of natural gas, which is cheaper than the solar portion.[93] Company officials at Southern California Edison project further system cost reductions of 30 percent,[94] which would make solar trough systems competitive in a wider range of markets.

Industry Outlook—Solar thermal energy will not likely be a competitive baseload energy source unless oil and gas prices rise significantly.[95] Although no major breakthroughs are envisioned that would lower costs below current projections, these reductions may be enough to make solar thermal a valuable source of supplemental energy. One market for which it may be uniquely qualified is toxic waste neutralization, where photochemical effects may be more effective than simple heat.

For the near term, the solar trough/natural gas hybrid system appears to be the most marketable. Utility studies suggest that in the long term central receiver and parabolic dish technologies offer the most cost-competitive generation if cost-effective storage technologies can be developed. The U.S. budget for solar thermal research, however, has steadily declined in the last 10 years, and the United States has lost its leadership to European countries in marketing solar thermal technology to foreign markets. Besides its environmental benefits, developing solar thermal energy technologies offers a potential multibillion-dollar domestic and international industry.

Photovoltaic Energy

Photovoltaic (PV) cells, which directly convert sunlight to electric current, have been used for years in calculators, watches, and space satellites. Other niche markets such as remote sites are also developing. These applications have sustained the PV industry while the technology has developed for using PV cells economically in the bulk power market. Although PV energy is more expensive than conventional energy for most uses, costs continue to drop. The present cost is now 20 to 30 cents/kWh—about five times the cost of conventional electricity.[96] With further advances in microelectronics and semiconductors, photovoltaics can become competitive with conventional power sources by 2010, maybe earlier. Some PV cells have already reached efficiencies of nearly 30 percent.

To capture solar energy, PV cells are grouped together in modules that are then linked in arrays on a large panel oriented toward the Sun. PV systems are used with battery storage in locations far from

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[90] Oak Ridge National Laboratory, op. cit., footnote 4, p. 105.

[91] Solar Energy Research Institute, op. cit., foonote 53, p. E-2.

[92] Weinberg and Williams, op. cit., footnote 88, p. 149.

[93] Solar Energy Research Institute, op. cit., footnote 53, p. E-1.

[94] Weinberg and Williams, op. cit., footnote 88, p. 149.

[95] Oak Ridge National Laboratory, op. cit., footnote 4, p. 105.

[96] Weinberg and Williams, op. cit., footnote 88, p. 149.

Photo credit: ARCO Solar, Inc.

Photovoltaic central station.

existing powerlines. The direct current electricity produced can be converted to alternating current and fed into the electric grid, but this is not yet cost-effective.

Technology advances have been focused on two types of PV module systems: the **concentrator system** and the **flat-plate collector.** Each system uses a variety of materials and configurations.

Concentrator Systems—In a concentrator system, lenses focus sunlight onto PV cells so that the equivalent of 50 to 1,000 Suns are focused on each PV cell. Such a system requires direct sunlight and uses expensive, though highly efficient, cells along with an inexpensive concentrator. A fairly complex, two-axis tracking system maximizes Sun exposure. At very high Sun concentrations, active cooling with circulating fluids is necessary.

The concentrator module could be the technology of choice for central station use in the near term because this option involves fewer materials possibilities. Moreover, the most promising advances for this system have been improvements in solar cell efficiency.

Technical Opportunities—Two semiconductor materials are being considered for near-term concentrator systems: silicon (Si) and gallium arsenide (GaAs). Silicon is the most mature PV technology. Improvements in silicon cells will involve incremental advances and improved mass production rather than basic technical advances.

Unlike silicon, GaAs does not degrade much at high temperatures, a significant consideration for use at 500 to 1,000 Suns, where active cooling can be necessary. Furthermore, only a few microns of

GaAs are enough to absorb all the solar radiation, whereas a few hundred microns of single crystal silicon (c-Si) are needed for the same job. However, growing thin films of GaAs in the quantity and quality needed is not yet feasible.

Concentrators that keep optical losses small and maintain focused radiation on cells throughout wind stress, thermal cycling, and tracking are the central focus of R&D programs. In the near term, 20-percent efficient concentrator modules can be achieved.[97]

Flat-Plate Collectors—This type of PV module system exposes a large surface area of interconnected arrays of PV cell modules to the Sun. This system uses cells cheaper but less efficient than those in the concentrator system. Unlike the concentrator system, flat-plate collectors can operate in diffuse sunlight, and no cooling system is required. Very little maintenance is required.

Flat-plate systems entail a large number of interconnections between a large number of cells. The integrity of these connections, and their protection against hostile elements in the environment, are more important than the protection of the cells themselves. Making cells as large as possible reduces the number of interconnections.

Technical Opportunities—Minimizing cell cost is critical for flat-plate modules. The complex design and manufacturing process for highly efficient concentrator cells may always be prohibitively expensive for one-Sun use. Focusing R&D efforts on improving automated high-yield processing of one-Sun cells may be more fruitful than changing cell design itself. Improvements in the quality of solar cell grade Si may also be possible.

A variety of cells can be used in flat-plate systems. They include single crystal, polycrystalline and ribbon silicon, and amorphous silicon.

Single Crystal Cells—The expense of growing and slicing single-crystal cells makes it unlikely that such cells will be used extensively in flat-plate technology. Other forms of silicon and new processing technologies are the best hope for improving flat-plate technology.[98]

Polycrystalline and Ribbon Silicon—Casting processes yielding large-grained polycrystalline silicon and techniques for making continuously pulled ribbon silicon may yield acceptable efficiencies at significantly reduced cost.

Thin-film Technology—The cheapest approach to PV energy conversion is the deposition of thin semiconductor films on low-cost substrates. Thin films are amenable to mass production and use only a small amount of active material. Materials used include copper indium diselenide, cadmium telluride (with small-area laboratory cell efficiencies of 19 percent), and amorphous silicon.[99] To be effective, deposition techniques must be developed to ensure high-quality and defect-free material within individual grains. If the thin film is polycrystalline, grain boundary effects must be minimized.

Amorphous silicon (a-Si) is interesting because only a thin film of inexpensive material is needed for high absorption and because large-area films of a-Si and multijunction a-Si cells can be made easily. However, efficiency is low and degrades over time. Research is focusing on improving efficiency by measures such as stacking cells (multijunction cells).

Wind Power

Wind power is the solar energy technology closest to being economically competitive in the bulk power market. In 1989, wind powerplants generated over 2 billion kWh of electricity,[100] at an average of 8 cents/kWh. At the best sites the cost was only 5 cents/kWh.[101]

Wind turbines convert the energy of the wind to rotating shaft power, which is converted to electrical energy. Horizontal axis wind turbines capture wind via propellerlike blades attached to a rotor mounted on a tower, similar in appearance to windmills of old. Vertical axis wind turbines look like giant eggbeaters: their two or three long, curved blades are attached to a vertical shaft at both ends. These turbines require no orientation to catch the flow of wind from any direction.

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[97] Oak Ridge National Laboratory, op. cit., footnote 4, p. 121.

[98] Ibid., p. 117.

[99] Ibid., p. 118.

[100] Solar Energy Research Institute, op. cit., footnote 53, p. 8.

[101] Jeanine Anderson, "New Third," *Public Power*, vol. 8, No. 3, May-June 1990, p. 23.

Wind is an intermittent resource that varies from region to region. Sites with small differences in wind velocity have great differences in energy output, because power output increases with the cube of the wind speed. Thus, an average wind speed of 19 miles per hour (mph) will produce 212 percent more available energy than will an average speed of 13 mph.[102]

Technical Opportunities—Although the costs of wind-derived energy have dropped dramatically since 1981, few of these reductions stemmed from technological improvements. Most of the savings resulted from standardization of procedures, mass production techniques, improvements in siting, and the scheduling of maintenance for periods of low wind.[103] New turbines are now able to remain in operation almost 95 percent of the time.[104] In addition, the lifetime of critical components for wind turbines has doubled in the last 10 years.[105]

DOE and industry analysts agree that within the next 20 years expected improvements in wind power system design will yield electric power at 3.5 cents/kWh for sites with only moderate wind resources.[106] Some Midwestern States, with average wind speeds of 14 to 16 mph, would be likely beneficiaries of such technology.

Additional improvements will derive from more sophisticated turbines that can adapt to the changing speed and direction of the wind, thereby helping provide more constant frequency power to a utility. Pacific Gas and Electric and EPRI are engaged in a 5-year project to develop, build, and test prototypes of a 300-kW variable-speed, wind turbine whose blades and electronic controls allow the rotor to turn an optimum speed under a variety of wind conditions. Advances in electronic controls that are sensitive to changing wind characteristics, and advanced materials that yield lighter, stronger components are expected to further improve wind energy competitiveness.

Wind power sites must have adequate wind, suitable topography, accessibility to both utility and transportation systems, and acceptability from environmental, regulatory, and public perception perspectives. Characterizing a site has proven costly and time-consuming, because techniques for extrapolating data from one site to another are not yet refined. Extensive, customized wind measurements are necessary at most sites to estimate and maximize their full potential. There is a need to establish a coordinated program for integrating, documenting, and disseminating wind measurements on a constant, long-term basis.

Photo credit: U.S. Windpower, Ed Linton, photographer

Small wind turbines.

In the past decade, U.S. funding for wind energy research dropped to $9 million per year, a tenth of what it was at its peak.[107] Technical improvements will be necessary if wind turbines, particularly small turbines, can compete without subsidies. More detailed information is also needed about wind resources, cost, and performance. Many industry observers recommend establishing minimum performance standard levels for turbine certification.

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[102] Solar Energy Research Institute, op. cit., footnote 53, p. F-1.

[103] Weinberg and Williams, op. cit., footnote 88, pp. 147-148.

[104] Solar Energy Research Institute, op. cit., footnote 53, p. 8.

[105] Anderson, op. cit., footnote 101, p. 26.

[106] Weinberg and Williams, op. cit., footnote 88, p. 148.

[107] Anderson, op. cit., footnote 101, p. 26.

In general, improvements in wind energy are expected to continue, and the cost of electric power from wind turbines in high-wind regions may become considerably lower than power from other sources. The rate of improvement will be heavily influenced by future trends in the avoided costs or "buy-back rates" offered by utilities to nonutility energy producers. If these costs are low or uncertain, technological development and application will be slowed. Conversely, high avoided costs, stimulated perhaps by rising oil and gas prices or shrinking reserve margins of generating capacity, might considerably accelerate the contribution of wind power.

Ocean Energy Systems

The ocean—with its waves, tides, temperature gradations, marine biomass, and other dynamic characteristics—contains an enormous amount of energy. Exploiting this resource has proved difficult.

Ocean thermal energy conversion (OTEC) exploits the difference between temperatures of surface water and water as deep as 1,000 m[108] to generate electricity. Differences as small as 20 degree Celsius can produce usable energy. Tapping this vast resource, particularly in tropical oceans, would produce an estimated 10 million megawatts of baseload power, according to SERI.[109]

Research has focused mainly on the closed-cycle and open-cycle OTEC systems for generating electricity. The closed-cycle system recirculates a working fluid, like ammonia, to power a vapor turbine for electricity generation. Warm seawater is used to vaporize the ammonia via a heat exchanger (evaporator). The expansion of the vapor runs the turbine. Cold, deep-sea water than condenses the vapor via another heat exchanger (condenser).

An open-cycle system uses warm seawater that is flashed into steam in a partial vacuum chamber as the working fluid to power a low-pressure steam turbine. The steam exiting the turbine is condensed by cold seawater. If a surface condenser is used, the condensed steam stays separate from the seawater, providing desalinated water. Effluents from either open- or closed-cycle systems can be converted to freshwater through a second stage evaporator/condenser system.

No commercial OTEC plants have been tested, but under some conditions, OTEC-derived electricity may be competitive in the next 5 to 10 years for small islands where power from diesel generators is very expensive. Use of OTEC domestically for electric power is unlikely except for coastal areas around the Gulf of Mexico and Hawaii.

It should also be noted that the basic OTEC technology—the conversion of large quantities of heat at low temperature differences to electric power—can also be used to exploit waste heat at industrial and commercial facilities. Many refineries, steel plants, chemical processing plants, etc. dump heat at much higher temperatures than are available in the ocean. Exploiting this energy would be much easier than building and operating an OTEC and would supply power right at a load center instead of out in the ocean. Similarly, thermal powerplants exhaust a huge amount of energy (60 to 70 percent of all energy input to the plant), though at lower temperature differences. A bottoming cycle using OTEC-type cycles could make an asset out of an environmental problem, and feed the power directly into the grid. Both these applications are likely to be economical long before OTEC.

Other ocean energy technologies that convert wave energy and tidal power receive much less attention than OTEC. The U.S. Government does no major wave R&D, but Norway, Britain, and Japan do. The greatest U.S. wave energy potential, with an estimated mean incident energy of 40 to 50 kW/m, is found on the West Coast. Wave energy during winter storms can reach over 200 kW/m, causing safety and design problems. Major technical challenges requiring engineering evaluations and development involve offshore siting (waves dissipate closer to shore), structural difficulties, the mooring, and the power transmission cable. Estimates for wave power for the Pacific Northwest are a yearly average power level of 1.64 MW, but a peak power of more than 3.3 MW during winter.[110]

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[108] The measure m is the difference between high and low tides, which creates a hydrostatic head like that in hydropower.

[109] Solar Energy Research Institute, op. cit., footnote 53, p. D-1.

[110] Ibid., p. D-9.

[111] Ibid.

The total U.S. tide potential has been estimated at 18,300 GW.[111] Only three coastal areas, however, are promising: one in Maine and two in Alaska. a minimum tidal range of 5 m is needed for tidal power to be considered practical. Research in microhydro technology may make tidal systems feasible at lesser tidal levels.

Municipal Solid Wastes (MSW)

About two-thirds of the solid waste generated by households and by commercial, industrial, and institutional operations is burnable and can be converted to energy.

Conversion Technologies—MSW can be converted to electricity and process heat by either mass combustion or refuse-derived fuel combustion. In mass combustion, MSW is burned with or without pretreatment or sorting of the inherent waste products. In refuse-derived fuel combustion, recyclable materials and noncombustible materials are first removed from the MSW. The remaining material is made into pellets.

Waste-to-energy facilities function much like a fossil fuel steamplant. The fuel is burned to heat water, and the steam drives a turbine to generate electricity. The steam can also be used in district heating/cooling systems. SERI estimates that current use of MSW for electricity totals 0.11 quads. Under current programs, that amount is expected to rise to 0.45 quads by 2010 and 0.57 quads if R&D is increased.[112] Most waste-fired capacity is owned by nonutility generators.

Another energy product, methane, can be recovered from MSW for use in natural gas systems via the anaerobic digestion of MSW's digestible components. If the cost of MSW disposal exceeds $40/ton, the net cost of MSW-derived methane may be as low as $3.50/MBtu, making it nearly competitive with the cost of delivering natural gas to the cities.[113]

A less economic recovery of methane is possible from the natural decomposition of MSW in landfills. Currently, 0.01 quad of landfill methane is recovered.[114] For safety reasons, other methane is collected from landfills and flared, because the volume is too low to be economical.

Several problems exist with present MSW approaches. MSW plants have higher capital and operating expenses than those of wood- or fossil-fired plants, mainly due to feedstock processing costs and to later emissions and solid waste disposal.

Some of these costs are balanced by credits for avoiding MSW disposal. Thus, overall costs of power generation average 7 cents/kWh but could alter depending on the economics of particular locales.[115]

A variety of technology improvements are being sought for reducing the costs of electric power generation and emission control, increasing the attractiveness of MSW as a fuel for electric powerplants. New ways are needed to dispose of dioxins, nitrogen oxides, chlorinated gases, solid residues, and ash. Automatic trash sorting to remove glass, plastics, and other recyclables would improve combustion and reduce disposal problems.

For methane production by anaerobic digestion of MSW, improvements are needed in solids loading rates and digestion efficiency. Also needed are improvements in the stability and control of digester operation. An accelerated program with industry involvement and cost-sharing could reach performance goals if tipping fees for MSW exceed the $25 to $50/ton range.[116]

Extensive commercial use of gasification of MSW may be economical already in areas where disposal costs are high (where tipping fees are above $100/ton at landfills).

OTHER FACTORS AFFECTING SUPPLY

Environmental Concerns

Perhaps of greatest concern is the greenhouse effect produced by gases emitted during fossil fuel combustion. These greenhouse gases, which include CO_2, methane, NO_x, and chlorofluorocarbons, trap heat in the atmosphere preventing its radiation into space. Global temperatures could increase by 2 to 9 degrees Fahrenheit over the next century if current emission trends continue. The anticipated rise in temperature could lead to devastating changes in climate, agriculture and forestry, and population shifts.

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[112] Ibid., p. B-20.

[113] Ibid., p. B-7.

[114] Ibid., p. B-8.

[115] Ibid., p. B-6.

[116] Ibid., p. B-11.

The United States is a major contributor to greenhouse gas emissions. U.S. carbon emissions from energy use account for 25 percent of the world total. Coal accounts for 35 percent of U.S. carbon emissions; petroleum, about 45 percent; and natural gas, about 18 percent.

A recent OTA report, *Changing by Degrees: Steps To Reduce Greenhouse Gases*, concluded that the United States can reduce CO_2 emissions by 20 to 35 percent from 1987 levels over the next 25 years but only with great difficulty. There are significant opportunities for reducing CO_2emissions in all sectors. To achieve this reduction, a serious commitment and the implementation of a variety of technical options and policy measures will be required. Emissions reductions may be costly, but no major technological breakthroughs are needed.

The implementation of CO_2 reduction measures will have far-reaching effects on the U.S. economy and energy supply picture. The switch to low or noncarbon fuels may revitalize the nuclear option, increase demand for natural gas, accelerate the growth of renewables, and limit production and consumption of coal. Attempts to limit coal use will result in significant social and economic impacts. At the very least, marginal, inefficient mines and coal-fired powerplants will probably close. Unemployment in the coal industry will rise. This will exacerbate economic problems that already beset some coal mining regions, especially Appalachia. Nevertheless, if we are serious about reducing CO_2 emissions, coal is the place to start.

The increased use of natural gas can deplete U.S. reserves and strain the distribution system. Prices could rise to very high levels. Also, the increased use of natural gas carries with it the risk of increased methane leakages.

These reduction measures will also result in ancillary environmental benefits that include reducing acid rain, urban smog, ozone depletion, groundwater contamination, and waste disposal. All of these environmental concerns can be addressed or are being addressed by regulations, so the advantages may be marginal. For an indepth analysis of technical and policy opportunities for reducing greenhouse gas emissions over the next 25 years, the reader is referred to the recent OTA report *Changing By Degrees: Steps To Reduce Greenhouse Gases*.

Another environmental concern is acid rain. The combustion of fossil fuels also produces sulfur dioxide and nitrogen oxide. As these pollutants are carried away from their sources, they can be transformed through complex chemical processes into secondary pollutants: sulfates and nitrates. These pollutants combine with water to form acid and fall as rain or other precipitation. Numerous chemical reactions—not all of which are completely understood—and prevailing weather patterns affect the overall distribution of acid deposition.

The best documented and understood effects of acid deposition are to aquatic ecosystems. The sensitivity of a lake or stream to acid desposition depends largely on the ability of the soil and bedrock in the surrounding watershed to neutralize acid. When the waters of a lake or stream become more acidic than about pH 5, many species of fish die and the ecosystem changes dramatically. In addition to the acidification of aquatic ecosystems, transported air pollutants have been linked to harmful effects to terrestrial ecosystems. Broad forested areas subjected to elevated levels of acid desposition, ozone, or both have been marked by declining productivity and dying trees, although it is uncertain how much of this is due to airborne pollutants. For an indepth discussion of acid rain, the reader is referred to the OTA report *Acid Rain and Transported Air Pollutants: Implications for Public Policy*.

The new Clean Air Act of 1990 caps utility emissions of SO_2 by the year 2000 at 8.9 million tons per year, a 10-million-ton reduction from 1980 levels. The new law also requires annual reductions of nitrogen oxides. Midwestern utilities and those located in Appalachia will be hardest hit by the cap. Most of the heaviest polluters are located in these regions. The biggest cuts in the first 5 years will be made by the heavy polluters. In addition, the law provides for a pollution credits trading system, which helps polluting utilities pay for acid rain cleanup. Utilities can reduce SO_2 emissions below their required limit-receive credits. These credits can be sold to other utilities and the cash used to defray costs of emissions control technologies. Credits are also given to "clean" utilities to grow beyond the cap.

The mandated emissions reductions will likely result in increased electricity costs to consumers, particularly in the Midwest, and may financially strain certain vulnerable utilities. Markets may be disrupted by an increase in the demand for low-sulfur coal at the expense of high-sulfur coals. This change in demand will result in increased unemployment in regions where high-sulfur coal is mined. The extent to which utility and industrial users would shift to low-sulfur coal depends on the relative cost advantage of fuel switching as opposed to removing sulfur dioxide by technological means (scrubbers). It is hoped that by providing financial incentives (pollution credits) to defray the costs of pollution control equipment, utilities will not switch to low-sulfur coal and thus save some high-sulfur coal-mining jobs.

Obstacles to a Nuclear Revival

Public Acceptance of Nuclear Power

Over the years, public concerns about reactor safety, costs, and waste disposal have had an impact on nuclear power will affect energy supply options in the future. The accidents at Three Mile Island and Chernobyl dramatized the hazards of nuclear power. Poor operations at some plants, especially when mishaps or small radioactive releases occur, serve as reminders. Nuclear reactors present risks to the public that are statistically much lower than other commonly accepted facilities such as dams, but the public will not find that credible until safety is no longer a controversial issue. Critics are unlikely to let the controversy die down as long as major accidents cannot be incontrovertibly proved to be of vanishingly small probability. Under present conditions, the public sees little reason to accept a potential risk for uncertain gains.

Utilities are very concerned over public acceptance of nuclear power. Recent public opinion polls have shown a resurgence in the fraction of people believing that nuclear energy will be essential. However, these polls do not tell the whole story since they ask questions only about general approval or disapproval. If a specific site were proposed for a nuclear powerplant, it is likely that the majority of people in the region would be opposed. Furthermore, public support would have to be widespread and with only minor opposition before utilities could be confident that there would be no reversal during construction and the operating lifetime of the plant.

There are many ways in which the public can make its opposition felt. Most directly, referenda have been held to shut down nuclear plants. One has passed on the Rancho Seco Plant in California, though that seems to have been more related to the economics of a poorly operated plant than to concerns over safety. Indirectly, the public also exerts pressure in courts, on local governments that must issue permits, and on state governments which must regulate rates of return on the investment and approve emergency evacuation plans.

At this point it is simply not possible to say with any assurance whether there will be a nuclear revival or what it would take to initiate one. If there is one, it will occur primarily because new plants are safer and cheaper than has been the recent norm and because alternatives are proving inadequate. However, neither safety nor cost will be easy to establish.

If costs and safety of nuclear power can be convincingly made favorable relative to other choices, a revival is quite possible, though by no means assured. This will not happen within the next few years, but by the mid-1990s demand growth is likely to mandate considerable new construction, and the industry will have had time to replace the memories of the present failures with a period of reliable operation and declining costs. Under such conditions, having the option of an economical reactor that has been thoroughly reviewed to minimize the risk of cost escalation or operating problems could prove attractive.

Financial Risks

The investment community provides another important disincentive for nuclear power. Investors generally believe nuclear to be much riskier than other options, based on the tribulations of utilities such as Public Service of New Hampshire, Long Island Lighting, the Washington Public Power Supply System, and General Public Utilities. Traditionally, regulated utilities provided limited profits, but also low risks. Some utilities have found their massive investments to be useless when they could not finish a plant because it proved to be unnecessary or too expensive, or failed to get a license, or were shut down for safety inadequacies. Some investors now refuse to buy stock or bonds in a utility building a nuclear plant, while others demand a large risk premium.

Very few people involved in operating nuclear powerplants believe that nuclear plants represent a significant hazard to the public, but failed construction projects and plants damaged by moderately serious accidents, e.g., Three Mile Island, pose important financial risks for the utility.

Capital Costs—A recent industry study predicted that a new nuclear plant would cost $1,400/kWe compared to $1,220 for a coal plant and $520 for a gas combined cycle plant. The levelized costs for the power would be 4.3 cents/kWh for nuclear, 4.8 for coal, and 6.1 for gas.[117] These figures are not verifiable because no plant has been started recently or under the conditions assumed in the analysis. In addition, industry has been generally optimistic on cost estimation, sometimes spectacularly so. Nevertheless, it suggests that nuclear power can still be competitive if the problems of the past can be avoided.

Nuclear Waste Disposal

Concerns about nuclear waste disposal also will have an effect on energy supply adequacy. The lack of proven technology and a known site for safely sequestering nuclear wastes has been one of the major factors behind opposition to nuclear power. To many people, it seems irresponsible to build reactors before we could be sure that waste products would never be a threat. The period required before the radioactivity of spent fuel decays to completely innocuous levels[118] is many times longer than recorded history, and no one can envision all the problems that might arise so far in the future. The many false starts, delays, and problems that have been encountered in the program to develop a nuclear waste disposal facility underscore the uncertainty of success.

Nuclear proponents point out that the need for waste disposal has always been recognized, and that the technical problems are not as formidable as they appear. Nuclear wastes are difficult to contain because they generate heat. The short- and mid-term components that produce almost all the heat largely decay within 200 years. After 1,000 years, virtually no radioactive material is left but plutonium and traces of a few other long-lived components. The waste can be stored in geological formations that have been stable for many millions of years, and even if conditions change, any leakage will be very slow (the long-lived wastes are largely insoluble in water and too heavy to be easily windblown). Such leakage should pose essentially no threat to people or the environment, especially in comparison to chemical wastes and other risks. In any case, the problem must be solved whether we build more reactors or not, because of all the waste that has been produced already in the commercial and weapons programs.

Yucca Mountain, part of the Nevada Test Site for nuclear weapons, has been selected as the site for the first Federal high-level waste repository. The climate is extremely dry, and the water table is about 1,000 feet below the proposed waste storage level, limiting the likelihood of leaching. The area is very thinly unpopulated, minimizing the number of people who could be at risk. Extensive testing and detailed analyses necessary to validate this selection are underway.

In addition to the natural protection of deep burial in a stable formation with little groundwater seeping down through the site, various manmade barriers will be applied to ensure protection, especially during the earlier, rapid decay rate stages. Waste can be blended into material, e.g., borosilicate glass, which hardens into a very stable mass. Vitrified wastes (or spent fuel) can also be encased in casks made of materials impervious to any plausible chemical or mechanical agent.

Other sites and different geological formations are probably also feasible. Yucca Mountain was chosen as much for political reasons as for technical.[119] Proposed nuclear waste disposal sites engender intense opposition (though sometimes also local support for the considerable economic benefits they can offer) which may be out of proportion to the risk entailed but can be just as difficult to overcome. Most experts are confident that nuclear waste can be safely contained, but a great many people are unwilling to accept these assurances. The risks to the local population are small, but they are not zero. Careless practices in the past that resulted in releases of radioactivity, and false starts such as the proposed site at Lyons, Kansas, ensure that the public will not blindly rely on the experts. Siting will be much easier if the program can establish a reputation for fairness and responsiveness to local needs. More high-level disposal sites will be needed, especially if nuclear power is to grow.

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[117] U.S. Council for Energy Awareness, "Advanced Design Nuclear Energy Plants: Competitive, Economical Electricity," January 1991.

[118] Plutonium has a half-life of about 24,000 years, and about eight half-lives or 200,000 years are required to reduce the radioactivity to the level of the original ore.

[119] Luther J. Carter, *Nuclear Imperatives and Public Trust* (Washington, DC: Resources for the Future, 1987).

Disposal of intermediate and low-level radioactive wastes may prove to be more troublesome in the long run because the volumes of materials are very much larger and the number of disposal facilities to be licensed and monitored is much greater. However, much of this material comes from research or medical purposes, not nuclear powerplants. Thus it is imperative to solve the problem whether or not nuclear power resumes growth.

Electric and Magnetic Fields

If electric and magnetic fields do prove to pose a risk to human health, the implications for the electric power industry will be great. Already, health effects are one of the most prominent concerns raised by people living near existing or proposed transmission lines. Several States have experienced increasing pressure to take regulatory action to protect citizens from the possible hazards posed by power frequency fields. By January 1989, seven States (Montana, Minnesota, New Jersey, New York, North Dakota, Oregon, and Florida) had already set limits on the intensity of electric fields around powerlines. Florida is the only State to adopt standards to limit the amount of both electric and magnetic fields.

Most of what we know today about the effects of exposure to these fields comes from three types of studies or experiments: Cell-level experiments, whole animal experiments, and epidemiological studies. Until relatively recently, there was little or no scientific evidence that electric and magnetic power frequency fields could pose a threat to human health. However, laboratory studies have now demonstrated that fields have effects on living cells and systems. Scientists are still investigating whether these effects have public health implications. In addition, several recent epidemiologic studies have suggested an association between exposure to power frequency fields and cancer. While these epidemiologic studies are controversial and incomplete, they do provide a basis for concern about the effects from exposure.

The research results to date are complex and inconclusive. Many experiments have found no differences in biological systems that have been exposed to fields and those that have not. It still is not possible to demonstrate that such risks exist, and they may not. However, the emerging evidence no longer allows one to conclude that there are no risks.

It is important to remember that exposure from transmission lines is one perhaps minor source. Exposure to local electric distribution lines, appliances, lighting fixtures, and wall wiring are more common and could play a more significant role in any public health risks. The OTA background paper *Biological Effects of Power Frequency Electric and Magnetic Fields* provides an indepth review of existing scientific evidence on biological effects and discusses policy responses to risk management.

Electricity Demand Uncertainty

Major shifts in electric power usage patterns have bedeviled utility planners and energy forecasters since events of the 1970s and 1980s made previous assumptions about inflation, consumer behavior, and economic growth obsolete. Throughout the past decade, the electric power industry has been saddled with expensive excess capacity as powerplants ordered in the 1970s came on line and demand growth fell below expectations. In the 1990s, the industry's problems with excess capacity appear to be receding, and in some regions of the country, reserve margins are tightening to the point that some industry analysts are warning of shortages.

Overall reserve margins are expected to decrease over the next 10 years. One of the results of lower capacity margins is that some utilities will have less flexibility in dealing with more severe situations. Another result could be greater reliance on older units, which in turn will increase maintenance requirements and result in more outage time. A number of factors could easily change supply adequacy or excess capacity into a shortage situation. Among the most important of these are delayed capacity additions and higher than predicted growth rates.

Among the analysts that have examined these prospects, there is some disagreement about when and where additional generation is needed. The disagreements are rooted in uncertainty over future growth in demand and the cost and performance of existing and planned capacity. In the face of the considerable uncertainties, conflicting views about which risks to take and who must bear those risks are inevitable. In recent years, few utilities have been willing to commit to construction of new baseload capacity, in spite of the continued aging of the existing generating plant stock and predictions from some industry and government planners that the country faces possible shortages in the early to mid-1990s. Meanwhile, the flow of new plant additions by utilities entering service as a result of orders placed in the 1970s is slowing to a trickle, although capacity additions by nonutility generators are increasing.

Nonutility Generation

Increases in nonutility generating capacity have been significant in recent years. The growth in cogeneration and small power production facilities has, to some extent, offset the slowing of utility construction of new capacity. According to the Edison Electric Institute, electricity sales to utilities from nonutility sources increased sixfold from 1979 to 1986 and 33 percent in 1988 and 1989.[120] Almost all of the sales have been to the investor-owned segment of the industry.

Also, nonutility generation is an important source of electricity in some States (California, Louisiana, Texas, Maine, Alaska, Hawaii) and is starting to become a national factor. Moreover, several regions, including New England and the Mid-Atlantic, will increasingly depend on nonutility generation additions to ensure supply adequacy or offset capacity shortfalls over the next 10 years.

A wide range of technologies can be used to cogenerate electric and thermal energy, e.g., steam turbines, open-cycle combustion turbines, combined cycle systems, and diesels. Much of the investment in new generating technologies, particularly cogeneration, has come from nonutility generators. For more information about cogeneration technologies, the reader is referred to the OTA report *Industrial and Commercial Cogeneration*.

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[120] Edison Electric Institute, op. cit., footnote 65.

Chapter 4

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Chapter 4

Potential Scenarios for Future Energy Trends

Previous chapters have described historical energy trends and identified the major components of our energy future. The relative emphasis on these various components will guide our energy future along one path or another. There is considerable variation among the potential paths. In general, the Nation can remain on a course that emphasizes conventional fossil supply patterns. Alternatively, an emphasis on high efficiency can reduce projections of energy demand. Such a shift would entail radical changes in energy supply planning and use, and in their economic and environmental impacts. If concern over global climate change increases, then increased emphasis on energy sources that do not produce carbon dioxide (CO_2)—nuclear power and renewable energy—could be necessary. These different paths entail many choices, such as which technologies to emphasize, and the technologies have large differences in their impact.

Of all the factors influencing energy trends, three of the most important are the growth rate of the economy (commonly measured by the gross domestic product (GDP)), the price of oil, and the status of technology. The GDP is a measure of the demand for the goods and services that require energy. Prior to the energy crisis of 1973-74, there was a general assumption that energy growth was intimately linked to GDP. That assumption has been disproved by the flat energy demand from 1972 to 1985 while the GDP grew by 39 percent in real terms.[1] Had historical trends held, U.S. energy use would have reached nearly 100 quads (quadrillion British thermal units) in 1985, up from 72.5 quads in 1972. Instead, only 74.9 quads were required that year.

Two factors accounted for this loosening of the connection between economic and energy growth. Improvements in energy efficiency accounted for almost two-thirds of the difference. Shifts in the structure of the economy (e.g., decline in energy-intensive heavy industries and growth in services that require relatively little energy) accounted for the remainder of the difference.

Since 1985, energy demand has resumed higher growth trends, increasing 8 percent by the end of 1988. Low oil prices and strong economic growth (the latter partly a result of the former), particularly in energy-intensive industries including steel and aluminum, appear to be responsible for this shift.

Neither economic growth nor the resultant effect on energy demand can be predicted confidently. The U.S. Department of Labor's moderate economic growth scenario for 1988 to 2000 assumes a 2.3-percent rate, lower than the 2.9-percent rate of the previous 12 years. This is consistent with other projections, but growth could be substantially higher or lower. In any case, it can be assumed that as long as economic growth is a national goal, demand for the services that energy provides will increase substantially.

The amount of energy that will be required to perform these services is a function of the efficiency with which it is used. As discussed in chapter 2, a particular service (e.g., transportation in a car, heating a house, making steel) can be performed in a variety of ways, some of which use far more energy than others. If the cost of energy rises (or if other incentives are applied), energy users will consider improving existing processes (e.g., insulating their house), buying more efficient equipment (e.g., higher mileage automobiles), or altering their behavior. However, rising energy costs also reduce consumers' ability to afford these investments.

Different forms of energy have different costs, but the most variable is petroleum. The price of petroleum is dependent to a large degree on political and market decisions that occur outside of the United States. The prices of other fuels are influenced by petroleum but are not subject to such large swings.

Changing technology will affect energy use by providing new options, especially as environmental regulations and resource constraints eliminate older options. For example, more stringent air emissions requirements could curtail industrial coal use, but emissions are easier to control in small facilities using the emerging technologies of fluidized-bed combustion and gasification. Improved technology is necessary for widespread use of solar energy and may be important for nuclear power. As discussed in chapter 2, a variety of technologies are available now in all sectors to raise efficiency, and many more could be developed and implemented.

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[1] This discussion is drawn from U.S. Congress, Office of Technology Assessment, *Energy Use and the U.S. Economy*, OTA-BP-E-57 (Washington, DC: U.S. Government Printing Office, June 1990).

PROJECTIONS FOR THE FUTURE

As discussed above, the qualitative aspects of the energy situation are not by themselves very useful in projecting future energy trends. Nor do they allow any quantification of the potential impacts of future policy options. For such purposes, scenarios have been derived from the analyses developed for the OTA report on climate change.[2] A simple accounting model modified the results of the energy/economic model of the Gas Research Institute, which in turn was based in part on the Data Resources, Inc. energy model, to estimate the effectiveness of various technical options for lowering CO_2 emissions. The reader is referred to the OTA report on climate change for a detailed explanation of the models used and the specific assumptions involved. Two scenarios are modifications of one of these cases in order to explore a higher emphasis on solar and nuclear energy. One additional scenario (number 2) involving higher demand was created and analyzed for this study.

These scenarios reflect the major issues discussed in chapter 1 that energy decisionmakers are likely to confront in the coming years: how to reduce CO_2 emissions to slow global climate change, should that prove necessary, and minimize other environmental and health impacts of energy use; how to reduce dependence on imported oil; how to assure that a reasonable diversity of supply options is available at the lowest possible cost.

All the scenarios except high growth used the same economic and energy cost assumptions: gross national product (GNP) growth of 2.3 percent (a moderate projection); price increases of 3.7 percent per year for oil, 4.8 percent for natural gas, and 1.7 percent for coal. These costs are based on production costs and do not necessarily reflect prices to consumers, which may be affected by temporary market perturbations and various policies, including energy taxes. The baseline projection, which assumes no major policy changes and no major constraints, is shown under scenario 1. Higher economic growth and lower energy prices are considered in scenario 2 to explore a future where very optimistic projections are realized. This scenario differs from the others in that a higher level of goods and services requiring energy are assumed. Scenario 3 is based on the moderate scenario in the OTA climate change report and emphasizes efficiency of energy use in order to reduce demand. Scenario 4 is based on the tough scenario and represents an intensification of the measures in scenario 3 to reduce energy demand. Scenarios 5 and 6 are modified versions of scenario 3 that exploit alternative energy sources (renewable and nuclear) to reduce emissions of CO_2, in contrast to the major emphasis on efficiency in scenario 4.

Collectively, these scenarios are representative of the main energy choices facing the country even though four of them were created to test CO_2 reduction decisions. Steps to reduce CO_2 emissions are largely congruent with steps to address the other energy issues. One notable exception is the development of synthetic fuels to reduce dependence on imported fuels, a topic discussed in scenario 2.

These scenarios should be viewed as guidelines only, not predictions. If one proves accurate, that will be largely accidental. Energy events of the last two decades have been too capricious and turbulent to allow much confidence that all problems in making energy projections have been anticipated. Unexpected disruptions will almost certainly occur, and so may some pleasant surprises, e.g., technological developments that permit the economic extraction of our vast domestic reserves of unconventional natural gas. The scenarios are sketches of plausible energy futures and what has to be done to get there. They provide a consistent framework for decisionmakers to compare the desirability of different energy futures we could work toward, and they suggest the costs and risks involved in the necessary decisions.

Scenario 1: Baseline

This scenario assumes no major policy initiatives are undertaken and present trends are largely continued. In particular, fossil fuel use continues to grow because it is the most convenient energy source available and is still affordable under the price increases assumed here. Total energy use rises slowly from 83.9 quads in 1989 to 112.4 in 2015, about 1 percent per year. Demand for electric power increases at 2.3 percent per year, equaling economic growth, as has been the case in recent years. The breakdown by fuel and end-use sector is shown in table 4-1. Electricity is listed separately because it is an intermediate carrier, neither supply nor demand, and accounts for the largest single use of primary energy.

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[2] U.S. Congress, Office of Technology Assessment, *Changing by Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991).

The baseline growth rate is slower than that of the past few years but faster than the prior 15 years. It is consistent with slowly rising energy prices and an economy that largely maintains its current mix of activities. Some improvements in efficiency are implemented so that energy intensity (energy per dollar of GDP) continues to decline. Of particular interest are the following:

- The highest energy growth is in the commercial sector. Industrial sector energy growth is the largest in absolute terms, but it remains modest for this sector, primarily due to reduced manufacturing growth. Transportation increases at a slightly slower rate than industry. The residential sector is essentially flat, largely because population growth is low.
- U.S. oil production is expected to decline from 9.73 million barrels per day (MMB/D) in 1990 to 8.61 in 2000 and 6.94 in 2015.[3] Even keeping to this schedule will require the discovery and exploitation of new fields, which are most likely to be offshore or in Alaska.
- Future domestic production of conventional natural gas resources will be supplemented by tight gas formations plus coal seam methane and Alaskan gas. Predictions of total production are tentative, largely because the economics of the unconventional resources are uncertain. This scenario projects a slowly rising production curve for about a decade, followed by essentially flat production.
- Coal remains the fuel of choice for electric power generation because of its long-term availability at low cost and the lack of major new environmental restrictions. Nuclear power declines after 2000 as plants are retired and no compelling reason arises to start many for operation before 2015.

Table 4-1—Baseline Energy Use and Supply
(quadrillion Btu)

	1989	2015
Demand		
Residential		
Natural gas	5.0	4.2
Electricity[a]	3.1	4.0
Oil	1.8	1.1
Coal	0.1	0.1
Renewables	0.9	1.5
Total	10.9	10.9
Commercial		
Natural gas	2.7	3.4
Electricity[a]	2.7	5.2
Oil	0.7	0.9
Coal	ne	0.1
Total	6.1	9.6
Transportation		
Oil	21.6	27.5
Natural gas	0.6	0.7
Electricity[a]	ne	ne
Total	22.2	28.2
Industrial		
Natural gas	8.3	7.7
Oil (fuel)	3.8	5.0
Oil (nonfuel)	4.4	5.7
Electricity[a]	3.2	5.3
Renewables	1.9	3.5
Coal	2.9	4.6
Total	24.5	31.8
Total demand[a]	63.6	80.5
Electricity[b]		
Coal	16.0	29.1
Nuclear	5.7	3.8
Gas	2.9	6.3
Oil	1.7	1.6
Renewables	3.0	5.7
Total	29.2	46.4
Supply		
Oil	34.0	41.8
Domestic	(18.3)	(12.0)
Imported	(17.0)	(27.8)
Exported	(1.8)	(0.0)
Synthetic	(ne)	(2.0)
Gas	19.5	22.3
Domestic	(17.5)	(16.5)
Imported	(1.4)	(5.8)
Synthetic	(ne)	(ne)
Coal	18.9	33.8[c]
Produced	(21.2)	(40.7)
Exported	(2.7)	(4.0)
Synfuel feed	(ne)	(2.9)
Nuclear	5.7	3.8
Renewable	5.8	10.7
Total	**83.9**	**112.4**

KEY: ne = negligible.

[a] Does not include conversion losses at powerplants, which make up about two-thirds of the total consumed there.

[b] All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

[c] Note that a total of 40.7 quads of coal are mined, 2.9 quads of which are converted into 2 quads of synthetic fuel, which are included under oil.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, tables 1, 2, 3, 4, 5, 11, 17, 25, 88, and 99; Office of Technology Assessment, 1991.

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[3] Derived from the U.S. Energy Information Administration, *Annual Energy Outlook 1990*, DOE/EIA-0383), Jan. 12, 1990, by OTA for a forthcoming update of its 1984 report *U.S. Vulnerability to an Oil Import Curtailment: The Oil Replacement Capability*.

- Security concerns increase with oil imports, but import growth rates are not so high that additions to the Strategic Petroleum Reserve (SPR) cannot keep up. By 2015, however, the Middle East supplies a very large and rising fraction of U.S. imports. Depending on the geopolitical environment at that time, the SPR might have to expand to several times its current size. The anticipated price of oil is substantially higher, which seriously aggravates the balance of trade.
- CO_2 emissions would rise almost 40 percent by 2015. While no environmental constraints are envisioned for the duration of this scenario, such a large additional contribution from the United States would pose a substantial risk of accelerating global climate change.
- The near doubling of coal consumption will aggravate problems in meeting local and national air quality standards unless better technology such as integrated gasifier, combined-cycle combustion becomes available.

Conclusions—This traditional approach is feasible if several conditions are met: 1) domestic oil and gas reserves prove adequate to support the projected production at reasonable prices; 2) chronic shortages of imported oil do not develop; 3) the costs of renewable energy become more competitive; 4) CO_2 and other pollution problems are not so serious as to restrict the coal option;. and 5) economic growth does not greatly exceed the assumed level. If these conditions are not met, energy prices will rise with tighter supply, and demand will shrink to fit (as it always does in principle), but not without likely economic penalties, e.g., increased inflation.

Scenario 2: High Growth

Scenario 1 does not represent an upper limit on energy growth even though there are more potential constraints on supply (e.g., resource depletion, siting difficulties, regulations, etc.) than on demand. In fact, there is no absolute upper limit on energy supply growth that could be usefully defined at this time.

Scenario 2 was created for this report to explore the implications of higher energy growth. It is not found in the OTA report on climate change.[4] Though even higher growth could be envisioned, the assumptions made for this scenario are sufficiently optimistic that higher growth is unlikely. Economic growth is assumed to be in the high range of projections, perhaps 3 percent, resulting in higher demand for energy services. Energy costs have to stay low despite higher demand, either because of technological breakthroughs or unexpected resource discoveries. No major new environmental regulations are expected in this scenario.

A guiding principle behind this scenario is that the United States maintains an orientation toward energy production rather than energy conservation. The result will be higher demand for energy services, tempered by the faster replacement of older, less efficient facilities and equipment. Total energy demand grows 1.7 percent annually, reaching 127 quads in 2015. Energy use in all sectors increases faster than in scenario 1. The industrial sector experiences 2-percent growth, consistent with a resurgence in manufacturing. The commercial sector rises faster at 2.7 percent, which is slightly above the rate assumed in scenario 1. Transportation energy demand increases 1.2 percent annually over the study period. Lower fuel prices provide less incentive to purchase efficient automobiles, and commercial traffic will be higher than in scenario 1. Residential sector energy demand grows at 1 percent with demand for new and larger houses; no such growth occurs in the base scenario. Table 4-2 summarizes the details.

Electricity demand increases 3 percent annually in this scenario. However, it is important to note that the additional power, relative to scenario 1, is produced with little additional fuel consumed. Under the conditions of this scenario—higher, sustained growth and greater confidence—utilities will be more willing to build new plants and replace older ones. New plants adopting modern technology should have significantly higher efficiency. Gas turbines should be over 50-percent efficient, and coal plant efficiency may reach 45 percent for some technologies. Transmission losses should be reduced as well, as a result both of new transmission technology and because much of the growth will be from small units close to load centers (e.g., cogeneration plants on-site at manufacturing facilities), minimizing the need for transmission. The net delivered efficiency assumed in this scenario is 35 percent, compared to 31 percent in the base scenario.

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[4] U.S. Congress, Office of Technology Assessment, op.cit., footnote 2.

Table 4-2—High Growth Energy Use and Supply
(quadrillion Btu)

	1989	2015
Demand		
Residential		
Natural gas	5.0	5.5
Electricity[a]	3.1	4.8
Oil	1.8	1.3
Coal	0.1	0.1
Renewables	0.9	1.5
Total	10.9	13.2
Commercial		
Natural gas	2.7	3.6
Electricity[a]	2.7	5.5
Oil	0.7	0.9
Coal	0.0	0.1
Total	6.1	10.1
Transportation		
Oil including synfuel	21.6	32.6
Alcohol (biomass)	ne	0.5
Natural gas	0.6	1.5
Electricity[a]	ne	0.7
Total	22.2	35.3
Industrial		
Natural gas	8.3	10.9
Oil (fuel)	3.8	5.6
Oil (nonfuel)	4.4	6.5
Electricity[a]	3.2	6.4
Renewables	1.9	3.8
Coal	2.9	5.3
Total	24.5	38.5
Total demand[a]	63.6	97.1
Electricity[b]		
Coal	16.0	27.4
Nuclear	5.7	8.2
Gas	2.9	7.0
Oil	1.7	1.6
Renewables	3.0	5.5
Total	29.2	49.7
Supply		
Oil	34.0	48.5
Domestic	(18.3)	(14.0)
Imported	(17.0)	(26.5)
Exported	(1.8)	(0.0)
Synthetic	(ne)	(8.0)
Gas	19.5	28.5
Domestic	(17.5)	(21.0)
Imported	(1.4)	(3.5)
Synthetic	(ne)	(4.0)
Coal[c]	18.9	32.9
Produced	(21.2)	(54.0)
Exported	(2.7)	(4.0)
Synfuel feed	(ne)	(17.1)
Nuclear	5.7	8.2
Renewable	5.8	11.3
Total	83.9	129.4

KEY: ne = negligible.

[a] Does not include conversion losses at powerplants, which make up about two-thirds of the total consumed there.

[b] All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

[c] Note that a total of 54.0 quads of coal are mined, 17.1 quads of which are converted into 12 quads of synthetic fuel, which are included under oil and gas.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, tables 1, 2, 3, 4, 5, 11, 17, 25, 88, and 99; Office of Technology Assessment, 1991.

Twenty years ago, these energy growth rates would have been considered unrealistically modest. Now they appear high, largely because we have learned that it is easier to control energy growth than to meet high demand growth. In addition, economic growth forecasts are lower and projected energy prices are higher. However, if energy prices remain at current levels (about $20 per barrel for petroleum and equivalent for other fuels), the higher growth of the late 1980s could continue. Energy prices significantly higher than those in scenario 1 would not be consistent with high demand growth (except for improbably high economic growth rates), because they would trigger efforts to increase efficiency of use.

Therefore, significant advances in energy production technology must be assumed for this scenario in order to control costs. Moreover, the modest energy price increases assumed here would be insufficient impetus to spur these advances. As a result, Federal and private sector efforts—especially for research, development, and demonstration (RD&D)—would be critical to achieving the supply outcomes. It must also be assumed for this scenario that CO_2 emissions are determined by policymakers to be a minor problem.

A substantial number of electric vehicles (EVs) are postulated for this scenario, largely because of local air pollution problems. About 2.4 quads of fuel would be required to produce and store the 0.7 quads of electricity that EVs would consume. This electricity would replace about 3.5 quads of oil, because EVs are more efficient than gasoline-powered automobiles. The use of natural gas in vehicles increases significantly as well.

In order to meet the supply projections, coal, natural gas, and nuclear energy would all have to be expanded significantly. Domestic oil production is almost certain to continue its decline, though improvements in enhanced oil recovery techniques could sustain production levels at existing fields. Exploration and development of presently protected areas in Alaska and offshore are probably necessary to keep the rate of production from declining faster than assumed here. Oil imports will rise considerably, unless synthetic fuel technologies are extensively applied. Renewable energy technologies are not likely to be widely competitive with relatively low cost conventional sources, but some penetration

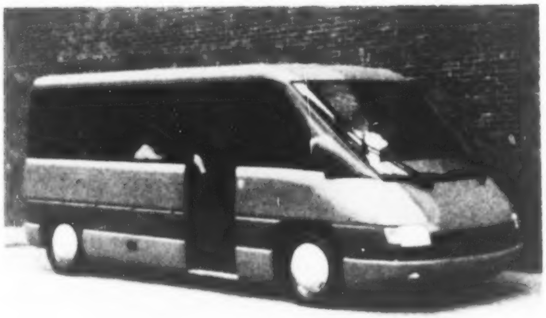

Photo credit: Electric Vehicles SA

Prototype electric minibus

is likely, and technological breakthroughs are possible.

Coal will be used both directly (primarily for electric generation as it is now) and for synthetic fuels. The additional 300 gigawatts of electric power output (GWe) of coal-fired generating capacity should present no insurmountable technical or resource difficulties, even though most plants will use relatively new technology (most probably integrated gasification combined cycle (IGCC)) to meet air pollution emission regulations. The efficiency of new plants should average about 40 percent, but system efficiency will be lower because of older plants on line and increased use of storage to meet peak loads.

Few coal plants have been ordered over the past few years because utilities have shied away from capital-intensive, long leadtime investments due to uncertainties about growth, capital availability, and regulatory treatment. This attitude is likely to change in a period of sustained economic growth. Both utilities and independent power producers (IPPs) could favor coal-fired plants if they are the lowest cost options in the long run. Even now, some gas-fired facilities are being designed to accommodate coal gasifiers should that prove more economical. The costs of constructing generating facilities and purchasing coal are likely to remain relatively stable and predictable over the next several decades under the assumptions of this scenario.

Synthetic liquid fuels from coal or oil shale are unlikely to be sufficiently competitive with petroleum by 2010 that much production capacity would be built without government incentives. However, security concerns over high petroleum imports may provide compelling policy reasons to ensure at least a modest level of such production. This scenario provides for liquid fuel production of 4 MMB/D by 2015. As discussed in chapter 3, several liquid fuel technologies could be used. At present, all of these technologies raise significant concerns over environmental impacts as well as costs, so major development and demonstration programs will be necessary in addition to promotional programs.

The national security rationale is less pertinent to synthetic pipeline gas, because foreign gas sources are more stable (Canada is the main supplier) and, unlike petroleum, the production of domestic natural gas can be increased appreciably. In fact, this scenario is largely contingent on an increasing supply of relatively inexpensive gas. Natural gas production, however, is unlikely to be rising by 2015, and may well be falling significantly. Therefore, the need for replacement sources may be substantial. In addition, an industry that produces synthetic oil would find it simple to produce synthetic gas, so the costs may be reasonable. Therefore, this scenario assumes that about 4 trillion cubic feet (Tcf) of synthetic gas will be produced annually.

Nuclear energy could be important in this scenario if the problems that have immobilized it are overcome. In particular:

- Costs must be predictable, stable, and competitive with coal;
- The institutions that build, operate, and regulate nuclear powerplants must perform their tasks more efficiently than has been the norm; and
- The public must be convinced that nuclear energy is safe, environmentally benign (including waste disposal), and in their best interest.

If these conditions are met, virtually any number of nuclear plants could be built. Yet the availability and competitiveness of alternatives to nuclear power suggest it is unlikely that huge numbers of new plants will be built. The viability of nuclear power will have to be demonstrated anew before any major commitment to construction is made. Even if relatively familiar light water reactor (LWR) technology is used, no reactor is likely to be ordered much before 1995 or completed before 2000.

Assuming a construction schedule of 5 years,[5] only those reactors ordered by 2010 would be ready for electricity generation by 2015. Since much of the industry would have to be revamped, only a few thousand megawatts of electric power output (MWe) per year could be supplied at first. Less familiar technology, e.g., high temperature gas reactors, will require longer to develop.

This scenario optimistically projects the construction of approximately 70,000 MWe to supplement existing nuclear capacity (about 100,000 MWe) by 2015. Accounting for existing plant retirements, total nuclear capacity of about 140,000 MWe would be online by 2015. Only a major national commitment to nuclear energy could result in faster growth, but that would be a high risk strategy considering the history of nuclear power in this country. Such a strategy is discussed under scenario 6. If no nuclear plants are ordered, an equivalent amount of coal- and gas-fired capacity would have to be added to meet the supply projections of this scenario.

Renewable supplies are only slightly higher than in scenario 1. The lack of urgency to replace fossil fuels assumed here leads to slow development of renewables, and the low costs of fossil fuels limit competitiveness. Much of the renewable energy depicted in table 4-2 is hydroelectric power, but contributions from wind, solar thermal, and photovoltaics could become significant over this period. The transportation sector is assumed to consume about half a quad of alcohol from biomass. Alcohol fuel could become quite important in urban areas for environmental reasons, but it is not clear how much will be made from biomass instead of coal or natural gas unless CO_2 emissions are a limitation. Therefore, most of the synthetic fuel in this scenario is derived from coal. As with nuclear energy, renewables have more promise beyond the timeframe of this scenario.

Conclusions—Where scenario 1 assumed no major policy initiatives and no major energy supply surprises, scenario 2 depends on several pleasant surprises: costs stay low because fossil fuels are plentiful; domestic oil production declines more slowly than some observers currently expect; natural gas production increases because discoveries keep abreast of depletion; and technology advances in these and other supply areas help keep these fuels competitive. In addition, features of the scenario probably would require policy measures to encourage production (e.g., synthetic fuel initiatives to limit imports and expanded offshore oil exploration and development). Finally, as noted above, it is assumed that no new major environmental constraints emerge.

If these assumptions prove out, the nation's mid-term energy future will present few problems. Some of the assumptions are likely to prove accurate, but depending on the entire package would be extremely risky, and would do little to prepare the country for longer-term problems such as climate change and the depletion of the lowest-cost fossil fuel reserves. Petroleum prices are almost certain to be much higher by the mid-21st century when U.S. production will be considerably lower than now. Whether or not serious global climate changes are imminent, they are likely eventually, probably by 2050. Rapid exploitation of fossil fuels would increase that risk and make the transition to alternative fuels more difficult and costly.

The energy system under this scenario is vulnerable to disruptions—petroleum import interruptions, environmental constraints, and increasing public opposition to energy facilities. Hence, policy measures encouraging production are likely to be required to ensure the supplies assumed in this scenario. Synthetic fuel to moderate reliance on imported petroleum has already been mentioned. To compensate for the higher rate of imports, the SPR would have to be enlarged. Nuclear power will require policy leadership to rebuild public confidence. Additional Federal RD&D on clean coal combustion could be necessary in order to reduce total emissions from a greater number of plants if current efforts prove inadequate. Siting policies may also be required to minimize delays to powerplants, transmission lines, and other facilities. Some of these measures are likely to be expensive and controversial.

The costs involved in this scenario are difficult to compare directly with the other scenarios, because the assumptions are not entirely consistent. Capital investments are higher than scenario 1, because more energy must be produced, but higher economic growth supports the new construction.

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[5] Small modular reactors might be installed faster with concurrent on-site preparation and factory construction, but this approach introduces additional uncertainties related to economics and operability that would delay their introduction.

Overall, this scenario is notable for its failure to take advantage of efficiency opportunities that make economic sense even at fuel prices lower than assumed here. In keeping with long-term past trends, efficiency improves, but only slowly because energy costs are a small portion of overall costs, and because relatively little attention is focused on efficiency. The one exception is the electric utility industry, where new generating technology is emerging with significantly higher efficiency.

Scenario 3: Moderate Emphasis on Efficiency

As has been noted several times in this report, many opportunities exist for reducing energy consumption in all sectors of the economy. Most of these opportunities require some investment. Some offer compelling economic benefits, while others are too expensive to warrant consideration unless energy costs rise considerably above expected levels.

This scenario explores the results if the policies discussed in the next chapter are implemented to encourage investments that would yield net economic benefits when amortized over the expected lifetime of the equipment, in the context of the fuel price increases noted at the start of this chapter. Few energy users make their decisions on this basis. Most consumers, insofar as they consider energy costs at all, look for a payback of no more than a few years on additional investment to reduce energy consumption, a rate of return greatly exceeding prevailing interest rates. Industrial users are the most cost-conscious, but even well-run manufacturing companies fail to make attractive investments to save energy for a variety of reasons, e.g., overall corporate strategy, technical and economic uncertainty, and capital spending limits. Therefore this strategy will require significant policy changes even though all the steps are in the long-term interests of the individual decisionmakers as well as the Nation.

Several significant advantages would accrue to the United States from a higher level of energy efficiency:

- If global warming is confirmed as a serious problem, reduced emissions of CO_2 would become important. Higher efficiency will be the most effective strategy to reduce carbon emissions over the next several decades. Even without clear indications of significant warming trends now, many analysts have argued that efforts to offset carbon emissions would be prudent now. In addition, lower demand for energy would reduce other environmental insults stemming from the production and use of fossil fuels.
- The economy would benefit, especially in the long-run, because energy inputs would be used at a more nearly optimal level. Thus, U.S. products would generally become more competitive in world markets.
- Resources of low-cost premium fuels would last longer because of the reduced demand for petroleum and natural gas. The forced transition to less convenient fuels could be delayed by a decade or more.
- Vulnerability to petroleum import disruptions would be lessened, and the SPR could be kept smaller.
- There would be less intrusion from energy facilities on society, which often resists such construction and operation.

The major drawback to this strategy is that the Government would have to induce people to do things that apparently most have no particular interest in doing. Tax credits, information programs, and other initiatives have had some impact, but the biggest single motivation for efficiency improvements appears to have been higher prices.[6]

The major effect of implementing this scenario is to moderate the growth of energy demand. Table 4-3 compares the energy supply and demand for this scenario with that of scenario 1. Overall, demand is down about 13 percent by 2015 from the base case but still up about 10 percent from current levels.

The efficiency improvements that would be implemented and their potential effect on energy consumption are listed in table 4-4. These measures are described in chapter 2. The assumption here is that each energy consumer always chooses the improvements that are expected to repay their incremental added costs with energy savings over their lifetimes. Considering the diversity of deci-

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[6] In the United States, the major exception to this general rule has been the corporate average fuel economy (CAFE) standard for light-duty vehicles. American made vehicles have nearly the same mileage as the equivalent models made in Europe or Japan, but the U.S. fleet has a lower average because Americans buy bigger cars. One of the major reasons for this difference is that gasoline costs several times as much in most other countries.

Table 4-3—Moderate Efficiency Scenario Energy Use and Supply (quadrillion Btu)

	1989	2015
Demand		
Residential		
Natural gas	5.0	3.6
Electricity[a]	3.1	3.3
Oil	1.8	0.9
Coal	0.1	0.1
Renewables	0.9	1.2
Total	10.9	9.1
Commercial		
Natural gas	2.7	3.0
Electricity[a]	2.7	3.4
Oil	0.7	0.7
Coal	ne	0.1
Total	6.1	7.2
Transportation		
Oil	21.6	24.8
Natural gas	0.6	0.7
Electricity[a]	ne	ne
Total	22.2	25.5
Industrial		
Natural gas	8.3	7.5
Oil (fuel)	3.8	4.4
Oil (nonfuel)	4.4	5.7
Electricity[a]	3.2	4.4
Renewables	1.9	3.2
Coal	2.9	3.3
Total	24.5	28.5
Total demand[a]	63.6	70.3
Electricity[b]		
Coal	16.0	17.8
Nuclear	5.7	6.6
Gas	2.9	4.1
Oil	1.7	1.5
Renewables	3.0	4.5
Total	29.2	34.4
Supply		
Oil	34.0	37.9
Domestic	(18.3)	(12.0)
Imported	(17.0)	(24.9)
Exported	(1.8)	(0.0)
Synthetic	(ne)	(1.0)
Gas	19.5	18.8
Domestic	(17.5)	(17.0)
Imported	(1.4)	(1.8)
Synthetic	(ne)	(ne)
Coal[c]	18.9	21.1
Produced	(21.2)	(27.5)
Exported	(2.7)	(5.0)
Synfuel feed	(ne)	(1.4)
Nuclear	5.7	6.6
Renewable	5.8	8.9
Total	**83.9**	**93.3**

KEY: ne = negligible.

[a] Does not include conversion losses at powerplants, which make up about two-thirds of the total consumed there.

[b] All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

[c] The 1.0 quad of synthetic fuel made from 1.4 quads of coal is included under oil.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, tables 1, 2, 3, 4, 5, 11, 17, 25, 88, and 99; Office of Technology Assessment, 1991.

Table 4-4—Potential for Energy Demand Reduction From Base Case by 2015 (quad/year)[a]

	Moderate efficiency	High efficiency
Residential buildings		
Envelopes	0.96	1.48
Heating and cooling	0.07	0.37
Hot water, appliances	0.89	1.41
Retrofits		
Envelopes	0.59	0.67
Lighting	0.44	0.59
Total	2.89	4.51
Commercial sector		
Envelopes	1.70	2.96
Heating and cooling	0.74	1.15
Water heating	1.55	2.22
Lighting	1.18	1.55
Office equipment	0.07	0.07
Cogeneration	0.15	1.41
Retrofits		
Envelope	0.59	0.59
Lighting	0.37	0.37
Total	6.29	10.36
Transportation		
New auto efficiency	0.59	2.70
New light trucks	0.37	1.92
New heavy trucks	0.30	1.77
Non-highway vehicles	0.37	0.89
Public transit	0.15	2.59
Improved maintenance	0.22	0.30
Improved traffic flow	0.89	1.04
Ridesharing, etc.	0.30	0.74
Total	3.11	10.73
Industry		
Cogeneration	0.59	4.07
Lighting	0.44	0.71
Electric motors	0.89	2.85
New processes	2.22	6.07
Process retrofits	1.41	1.48
Total	5.62	17.06

[a] Because of the form of the data and the conversion method, all values are approximate and should be used for general guidance only. Totals are not always equal to the sum of the parts because maximum values may be inconsistent, and other factors may be involved.

SOURCE: Derived from U.S. Congress, *Changing by Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991), table A-3.

sionmakers and their different situations, this is a highly artificial assumption. However, regulation (e.g., fuel economy standards for automobiles) and transfer of decisions to energy service companies (perhaps gas and electric utilities with incentives to increase efficiency) could produce many of the needed choices. In addition, unanticipated, improved technology is likely to appear that makes possible even greater savings. In general, therefore, this assumption provides a useful standard to compare the potential efficacy of policies, as described in the next chapter.

Residential/Commercial Sector

In the residential/commercial sector, new buildings require only 50 percent of the energy used in current new buildings for heating because of better construction techniques, insulation, and windows. Improved lighting and equipment provide additional savings. For the most part, the technology for these improvements is familiar. Some of the gains depend on the commercialization of new technology, e.g., heat pump water heaters, but none of the required advances is particularly dramatic or risky. Nor are consumers required to accept many technologies that would be significantly more difficult to manage than existing equivalents.

The uncertainties are primarily with the decisionmaking to implement the improvements, particularly what it will take to induce consumers to invest in more expensive houses and appliances in order to save on operating costs. In no case would the additional investment be extremely high (e.g., a new house might cost a few thousand dollars more because of improved insulation and appliances). However, the decisionmaking in this sector has been less predictable than in the others. Overall, energy use in the residential/commercial sector could actually decline by 2015 with these changes despite a substantial increase in per capita wealth.

Electricity use increases in both the residential and the commercial sectors. Natural gas declines in homes because the average thermal efficiency of houses increases. Natural gas and electricity will dominate the supply of energy under any conditions. The balance between the two will depend on relative costs and availability, as well as the success of various RD&D and commercialization programs. Policy decisions will strongly influence the successful implementation of new technologies, and the implications for the country of the various choices are significant, as described in the following chapter. Oil is likely to continue its decline because of cost and convenience considerations. Wood and other forms of solar energy could be increased by various policy initiatives but, as discussed in scenario 5, the initiatives would have to be powerful for the additional contribution to be large in this timeframe. In the long term, renewables could become very important in the residential/commercial sector.

Transportation Sector

Energy use in the transportation sector is much less likely to drop than in the residential/commercial sector, but the growth rate can be slowed. Cost-effective improvements in the mileage of new cars, trucks, and airplanes will reduce demand significantly, but the increase in miles traveled will outweigh them. In the long term, improved mileage will make a dramatic difference. With improvements to already existing technology, the fuel economy of new automobiles in this scenario increases to 39 miles per gallon (mpg) by 2010, as compared to 36.5 mpg in the base case and 27 mpg now, using only evolutionary improvements to existing technology, as discussed in chapter 2. However, over the next 20 years, nontechnical measures, e.g., increased van pooling, improved vehicle maintenance, and reinstatement of the 55 mile per hour (mph) speed limit, will have more impact.

Achieving major fuel economy gains in the transportation sector may be hindered by conflicting demands. For example, reducing vehicular emissions often results in some compromise to fuel efficiency and vice versa. The expected growth of alternative fuels resulting from the 1990 amendments to the Clean Air Act may reduce oil imports but does not promise greater efficiency. Indeed, the recent revisions to the Clean Air Act mandate several changes that will affect how the transportation sector uses fuel. Gasoline will still be the dominant fuel by 2015, but the large, powerful cars that many consumers prefer now will be squeezed between demands for cleaner emissions and higher mileage. In some metropolitan areas, alternative fuels, e.g., methanol and electricity, will be favored, but it is assumed here that their penetration is too small to be significant.

Industrial Sector

The diversity of the industrial sector complicates any analysis of future fuel use. Several fuels, various processes, and different industries with a variety of financial situations must be considered. Over the past 17 years, industry has made notable strides in increasing energy efficiency for economic reasons. More improvements are possible, particularly through electric motor improvements, process modification, lighting, and energy management systems, and with processes specific to certain industries, but the gains will be relatively modest. About 15 percent

(4 quads) of the energy required in the base case is saved by these measures by 2015, but a net increase of 4 quads over 1987 is still required.

Fuel shifting within the industrial sector is relatively easy for applications such as process heat and cogeneration (about 60 percent of all energy used in manufacturing), but quite difficult or impossible for other categories. Many boilers and heaters incorporate dual-firing capability to switch between oil and natural gas as economics and emission regulations dictate. Coal can also be a major energy source, actually surpassing oil by 2015 in this scenario. Policy incentives or disincentives focused on natural gas and coal are likely to have more effect than those aimed at efficiency.

Electric Power Sector

The electric power sector consumes more primary energy than any of the three sectors discussed above. One of the main issues related to electric power involves nonfossil energy sources, which are discussed in scenarios 5 and 6. There are also some important options to raise the efficiency of the sector through improved generation and transmission, but few are implemented, because so little new generating capacity is required. In this scenario, demand for electricity is lower than in the base case because the efficiency of use increases. Demand rises from 2.7 trillion kWh (kilowatt-hours) in 1987 to 3.4 trillion kWh in 2015, compared to 4.6 trillion kWh in 2015 in the base case.

In the long term, new plants can be significantly more efficient than existing ones. The efficiency of new technologies, e.g., fuel cells and intercooled steam-injected gas (ISTIG) turbines, may approach 50 percent, higher than any existing technology. Advanced pulverized coal or IGCC technologies should also have significantly higher efficiency than current plants. The competitiveness of the new technologies will depend in part on environmental constraints. Tighter restrictions on sulfur oxides (SO_x) and nitrogen oxides (NO_x) will favor new technologies that can be cleaner as well as more efficient.

Conclusions—There are two major reasons why policymakers might choose to move the country toward this scenario. One is economic: this is the least cost scenario, and implementing it (or some of its major features) would improve the economic well-being of the country and its international competitiveness. The other reason is environmental: reducing energy use generally, though not always, reduces emissions of pollutants from both the use and supply of energy. This scenario would provide many environmental benefits without drastic curtailments. It represents a moderate response to concerns over global climate change and reducing CO_2 emissions, consistent with the conclusion that the problem has not been verified at present but may be serious in the coming decades.

As noted above, however, this scenario will not occur by itself. There are too many constraints and market imperfections for people to make all the necessary decisions that would be required to implement this level of efficiency. Policy initiatives that would help overcome these constraints are discussed in the following chapter.

Scenario 4: High Emphasis on Efficiency

Extreme measures to improve efficiency could be justified under some circumstances. Perhaps global warming will be confirmed as an imminent problem with potentially devastating consequences, or international political instability will severely threaten the supply of petroleum. Even in highly efficient countries, almost any activity consuming energy could be accomplished with much less. If energy were to become very expensive or limited in availability, the number of viable, alternative approaches to reduce energy use would increase. This scenario incorporates measures that are equivalent to the most efficient that have been demonstrated to date and assumes that these are widely applied. Table 4-5 shows the energy use that results. Table 4-4 lists the measures that are implemented.

Residential Sector

Energy use in the residential sector drops sharply compared to the last scenario. Residential buildings are constructed to such high standards that heating requirements in new northern homes are reduced 85 percent from average existing stock, and air conditioning by 45 percent. These are extremely optimistic projections based on the assumptions that essentially every new house will match the most efficient houses currently available and be maintained in that condition.

Superinsulation, including the latest developments in windows (which are quite expensive) can achieve as much as a 75-percent reduction in

Table 4-5—High Efficiency Scenario Energy Use and Supply (quadrillion Btu)

	1989	2015
Demand		
Residential		
Natural gas	5.0	2.9
Electricity[a]	3.1	2.6
Oil	1.8	0.8
Coal	0.1	ne
Renewables	0.9	0.6
Total	10.9	6.9
Commercial		
Natural gas	2.7	3.8
Electricity[a]	2.7	1.7
Oil	0.7	0.3
Coal	ne	0.1
Total	6.1	5.9
Transportation		
Oil	21.6	17.7
Natural gas	0.6	0.7
Electricity[a]	ne	0.1
Total	22.2	18.5
Industrial		
Natural gas	8.3	7.7
Oil (fuel)	3.8	3.3
Oil (nonfuel)	4.4	5.7
Electricity[a]	3.2	3.2
Renewables	1.9	2.2
Coal	2.9	1.5
Total	24.5	23.6
Total demand[a]	63.6	54.8
Electricity[b]		
Coal	16.0	5.3
Nuclear	5.7	6.8
Gas	2.9	5.3
Oil	1.7	0.2
Renewables	3.0	5.2
Total	29.2	22.8
Supply		
Oil	34.0	27.8
Domestic	(18.3)	(12.0)
Imported	(17.0)	(15.8)
Exported	(1.8)	(0.0)
Synthetic	(ne)	(ne)
Gas	19.5	20.3
Domestic	(17.5)	(17.5)
Imported	(1.4)	(2.8)
Synthetic	(ne)	(ne)
Coal	18.9	7.0
Produced	(21.2)	(13.0)
Exported	(2.7)	(6.0)
Synfuel feed		(ne)
Nuclear	5.7	6.8
Renewable	5.8	8.0
Total	83.9	70.0

KEY: ne = negligible.

[a] Does not include conversion losses at powerplants, which make up about two-thirds of the total consumed there.

[b] All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, tables 1, 2, 3, 4, 5, 11, 17, 25, 88, and 99; Office of Technology Assessment, 1991.

residential heating. Exceeding 75 percent will require meticulous attention to design, construction, and materials, and possibly, compromises on appearance and lifestyle as well. For example, houses and their windows may have to be oriented toward the sun (rather than toward the street), or the number of windows could be reduced.

Very tight houses require ventilation systems to keep indoor air pollution at tolerable levels. As air exchange is reduced by tightening shells, problems arising from indoor air contaminants (radon, NO_x from natural gas cooking, vapors from building materials) and irritants (particulates, aerosols) will worsen unless countervailing measures are taken. Fireplaces and woodstoves would be incompatible with supertight houses, because they require continual ventilation while in operation. Even with heat recuperators, significant heat losses from ventilation systems will interfere with the 85-percent heat reduction goal. As a result, multiunit buildings may have to be encouraged as an important alternative to single family homes in order to achieve the energy projections for this sector.

Existing building shells are aggressively retrofitted in this scenario. Energy savings of 20 to 30 percent are anticipated. This goal is less controversial than that for new houses.

In addition, appliances will have to be as efficient as currently feasible. Electric or gas-fired heat pumps or pulse furnaces would replace conventional furnaces in new construction. Electric heat pumps would be at least 50-percent more efficient than those in use now. Water would also be heated with heat pumps. Lighting will be primarily with fluorescent or halogen bulbs. Important appliances such as refrigerators, ovens, and clothes dryers increasingly are based on new technology that cuts energy consumption dramatically.

These changes will add substantially to the cost of buying a home, perhaps $6,000 to $8,000 for the supertight envelope. Total costs, including lost living space because of thicker walls and efficient equipment would be higher (though heating and cooling equipment might be cheaper than in a conventional house because small units would be adequate). The energy costs of the buildings are quite low, but the savings may not be commensurate with the additional capital costs if the price of energy to the consumer follows the assumptions listed earlier in this chapter.

Commercial Sector

Energy consumption in the commercial sector drops 30 percent relative to the moderate projection scenario. Buildings require 25 percent of the current average for heating, and appliances are as efficient as the best available now. The most notable shift is the replacement of purchased electricity with natural gas, some of which is used in cogeneration.

Transportation Sector

The transportation sector produces large savings relative to the last scenario, mostly because mileage standards on new automobiles are raised sharply. The previous scenario raised the 2010 average from the 36.6 mpg of the base case to 39.0 mpg, which would have little effect on consumer choice or cost. The increase to 55.0 mpg here would require an aggressive emphasis on new technology, such as adiabatic diesel engines, lighter materials, and continuously variable transmissions. Some shift toward smaller cars in the fleet mix would be required to meet this standard if the technological improvements prove inadequate. Only one or two models on the market now are rated at 55 mpg, and these are very small. In addition, there will have to be a strong emphasis on car pooling, public transportation, and advanced traffic control. The 55-mph speed limit is reinstated under this scenario as well.

Although they are not emphasized here, alternative fuels and electric vehicles could play a large role under the conditions of this scenario. If the concern is over CO_2 emissions, then the replacement of gasoline by methanol from biomass would have substantial benefits. Methanol from natural gas would be beneficial (but less so), while synthetic fuels from coal or oil shale would be very counterproductive as an option to reduce CO_2 emissions. If energy security is the concern, any of these alternative sources would serve to reduce imports of petroleum and so would be consistent with this scenario. However, security is unlikely to be the major issue driving this scenario, because it would be cheaper and easier to enlarge the SPR. Alternative fuels and electric vehicles are discussed in the last two scenarios.

Industrial Sector

Energy consumption in the industrial sector would decrease more than 25 percent from current levels under this scenario. The efficiency gains are even greater than this, but economic growth offsets many of them. Process changes provide the greatest energy savings, followed by improved maintenance, more efficient electric motors, and cogeneration growth. Some of the new processes will require research and development (R&D) and probably Government support for demonstrations. Industry is willing to accommodate changes to improve energy efficiency, but only if the changes are demonstrably cost-effective and of acceptable risk, suggesting that an increase in the price of energy would be the most effective motivation. The major difference between this scenario and the previous one is that the universe of acceptable technological options to save energy expands, and increased use is made of technologies implemented in scenario 3. Some of the most important changes are in industry-specific processes, e.g., direct steelmaking and biopulping for papermaking.

Widespread implementation of many of these options would require major alterations to old facilities or the construction of entirely new ones. These major changes would not be done purely for energy reasons, though the energy savings would represent a significant part of the economic benefits. Therefore, this scenario is most likely to be initiated as part of an overall upgrading of much of the industrial infrastructure in this country. Such an overhaul is beyond the scope of this report, but it should be noted that considerable promise exists for major industrial gains in both energy efficiency and economic competitiveness.

Electric Power Sector

Efficiency gains in the electric power sector are slightly greater than in scenario 3. Improved efficiency in the other sectors controls electricity demand to the point where few (if any) new generating facilities are required. While this eliminates a source of higher efficiency, many generating plants would have to be retired, and these are likely to be the least efficient ones. Retrofits to existing plants would raise efficiency modestly. If further gains are required in the electric power sector, existing plants could be replaced with new ones.

The motivation for much greater efficiency is important here. If the goal is to increase energy security, then replacing existing plants has little value. Only 5 percent of the oil consumed in this country is used to generate electricity, and most generating plants burn coal, which is not a security problem. If the motivation is to reduce CO_2 emissions—generating stations produce over one-third of all the CO_2 emitted in the United States—then replacements may be warranted. However, the environmental benefits of replacing an old coal plant with a new one are much smaller than the benefits of replacing it with a nonfossil plant. This approach is considered in the next two scenarios.

Therefore the major assumption of the high efficiency scenario is that most existing coal plants are retired by 2015. Coal consumption in the sector drops by almost two-thirds. As noted below, this would have extremely serious economic consequences in some coal-producing areas. Most new construction is highly efficient combined-cycle, gas-fired technology. Some nuclear (5 GWe) and renewable (15 GWe, mostly hydroelectric) energy is also included. In addition, the improved operation of existing plants raises their efficiency by about 5 percent, as in the previous scenario.

Conclusions—This scenario is notably more successful in reducing energy demand than the previous one, but it relies on measures that would be even more difficult to implement. Housing and automobiles would be significantly more expensive to purchase, though cheaper to operate. Much new technology, particularly in the transportation and industrial sectors, is assumed to be available and reliable. Industry may find more compensating advantages than consumers, but companies would still find their planning processes heavily influenced by this major effort to reduce national energy use.

Therefore, this scenario is very unlikely to be implemented unless driven by major national threats. As noted above, the only threats that appear sufficiently ominous over the next 25 years are severe oil import disruptions and global warming. By itself, this scenario would not solve either problem, but it probably represents a practical upper limit for national demand reduction efforts.

The two remaining scenarios are alternative, though not necessarily incompatible, approaches to mitigating the threat of global warming. In the long term (before the end of the 21st century), some of the measures outlined in these three scenarios may be necessary merely from the worldwide depletion of petroleum if synthetic fuels prove too expensive to adopt on a wide scale. Whether any threats justify this level of action is a judgment that cannot be determined analytically at this point.

Scenario 5: High Emphasis on Renewable Energy

Renewable energy sources (solar and geothermal) have considerable appeal from an environmental perspective. In most cases, the energy already exists naturally, and there are few harmful emissions from its use. However, with some exceptions, renewables currently are not economically competitive with fossil fuels or nuclear energy. As discussed in chapter 3, some renewable technologies show considerable promise for near-term competitiveness on a wide scale. Policy intervention could assure a much more rapid penetration than assumed in the previous scenarios. The impetus could be concern over global warming, other environmental issues such as air quality, or energy security.

However, it does not appear that any of these options will ever seem inexpensive by current standards. Hence, a high dependence on renewable energy should start with an economy that has built in as much efficiency as practical. This scenario builds on the energy distribution in scenario 3 (moderate efficiency) but shifts some of the supply from fossil to renewable sources. Table 4-6 outlines the supply and demand. As each sector will adopt renewables for unique functions, they are discussed separately.

Residential/Commercial Sector

The major direct use of renewables in the residential/commercial sector would be passive and active solar heating. As in the previous scenario, wherever possible, buildings would be oriented toward the sun and designed to maximize capture of solar energy in the winter while excluding it in the summer. Active panels to collect solar energy for both heat and hot water would become common. The use of firewood (now the dominant use of renewable energy in buildings) would also increase, but environmental and safety considerations suggest that firewood should not be a favored energy source. Processed fuels from biomass should be more benign. By 2015, the solar contribution could be displacing 1.0 quad of fossil or electric heating in buildings, and geothermal another 0.5.[7] In addition, biomass could be increased by 0.5 quad. The total additional renewable contribution to the two sectors is 2 quads.

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[7] The values in this section are derived from Solar Energy Research Institute et al., *The Potential of Renewable Energy; An Interlaboratory White Paper*, prepared for the U.S. Department of Energy, SERI/TP-260-3674, DE90000322 (Golden, CO: Solar Energy Research Institute, March 1990).

Commercial buildings may be less appropriate than residences for solar heating, because most are too large for on-site collectors. Furthermore they use heat for unique functions and often extended periods (hospitals, restaurants). However, commercial building owners can also arrange for service companies to supply heat or cooling from off-site solar stations.

The size of the solar collector industry has decreased greatly since the 1970s from the loss of tax credits and the drop in fossil fuel prices. Rapid growth would risk repeating the experience of the 1970s, when inadequate designs and unskilled or dishonest installers plagued the industry. The technology is much better now, but controls to ensure that the solar contribution is achieved efficiently would be prudent.

Other applications for renewable energy include electricity generation and the replacement of natural gas with hydrogen, which could be produced by photovoltaics. Alternatively, synthetic gas could be produced from biomass. These options also apply to the sectors discussed below.

Transportation Sector

The transportation sector would use fuels derived from biomass. If advances in plants, cultivation, and processing are successful, methanol from wood or herbaceous crops is the most likely fuel though some of the ethanol technologies are promising. By 2015, as much as 1.2 quads could be supplied, displacing 0.6 MMB/D. Moving toward methanol would reduce air pollutants such as ozone, though handling would have to be stringent to minimize toxic exposure. Energy security would be well served, because most of the feedstock would be domestic.

However, the long-term transition to a biomass-derived, methanol-fueled fleet would be very difficult. If biomass is not to interfere with food production, presently unused farmland or forests would have to be cultivated. As much of the farmland would be marginal, environmental problems, e.g., erosion, could be potentially serious. A major industry for fuel processing and distribution would have to be established. A dual distribution system for methanol and gasoline would be required for many years. Automobiles would be either multifueled, which is less efficient, or limited to one type of distribution, as are diesel cars now. Problems such as starting the engine in cold weather would need to be solved. The transition would be eased if methanol is first introduced as an additive to

Table 4-6—High Renewable Scenario Energy Use and Supply (quadrillion Btu)

	1989	2015
Demand		
Residential		
Natural gas	5.0	3.3
Electricity[a]	3.1	2.8
Oil	1.8	0.7
Coal	0.1	ne
Renewables	0.9	2.3
Total	10.9	9.1
Commercial		
Natural gas	2.7	2.7
Electricity[a]	2.7	3.0
Renewables	ne	0.9
Oil	0.7	0.5
Coal	ne	0.1
Total	6.1	7.2
Transportation		
Oil	21.6	23.6
Natural gas	0.6	0.7
Renewable	ne	1.2
Electricity[a]	ne	ne
Total	22.2	25.5
Industrial		
Natural gas	8.3	6.7
Oil (fuel)	3.8	3.7
Oil (nonfuel)	4.4	5.7
Electricity[a]	3.2	4.4
Renewables	1.9	4.8
Coal	2.9	3.2
Total	24.5	28.5
Total demand[a]	63.6	70.3
Electricity[b]		
Coal	16.0	12.1
Nuclear	5.7	4.3
Gas	2.9	2.7
Oil	1.7	1.2
Renewables	3.0	11.3
Total	29.2	31.6
Supply		
Oil	34.0	35.3
Gas	19.5	16.0
Coal	18.9	15.4
Nuclear	5.7	4.3
Renewable	5.8	20.5
Total	83.9	91.5

KEY: ne = negligible.

[a] Does not include conversion losses at powerplants, which make up about two-thirds of the total consumed there.

[b] All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, tables 1, 2, 3, 4, 5, 11, 17, 25, 88, and 99; Office of Technology Assessment, 1991.

gasoline, and then as a pure fuel for urban fleets, before individuals are expected to purchase cars that burn only methanol.

An alternative is cars powered by solar-generated electricity. Electric cars have even more environmental advantages than methanol cars, emitting almost no pollution when the electricity is produced cleanly. However, significant storage improvements would be necessary before electric cars could expand beyond small niche markets. In this scenario, the penetration of electric vehicles is assumed to be small relative to methanol. (The following scenario reverses this assumption.) Solar electricity is discussed below. If the technology can be developed, powering cars with hydrogen produced from solar electric plants might be superior to using the electricity directly. The infrastructure required for hydrogen would be quite different, but the overall environmental, economic, and social impact probably would be about the same.

Industrial Sector

The industrial sector already uses substantial amounts of biomass, primarily through combustion of wood wastes by the forest products industry. Biomass use could be expanded about 1.5 quads by 2015.

Industry uses primary energy mainly as process heat. Most process heat requires temperatures far greater than that produced by flat solar panels, but such high heat is easily obtainable by the type of collectors used in solar thermal electric plants. Industry could replace a significant fraction of its fossil fuel use with solar energy, but only if long-term storage technology is perfected as well. No company would risk plant shut downs from something as common as several cloudy days. Backup energy supplies can be arranged, but they would add considerably to costs and complexity, which could deter many companies from adopting these technologies at all.

Penetration of these technologies is likely to be slow, because most industrial energy consumption in 2015 will be in facilities that have already been constructed and that are not necessarily appropriate for solar energy. This scenario assumes that industrial solar energy use will be small in 2015, though it could expand considerably beyond the time frame of this scenario.

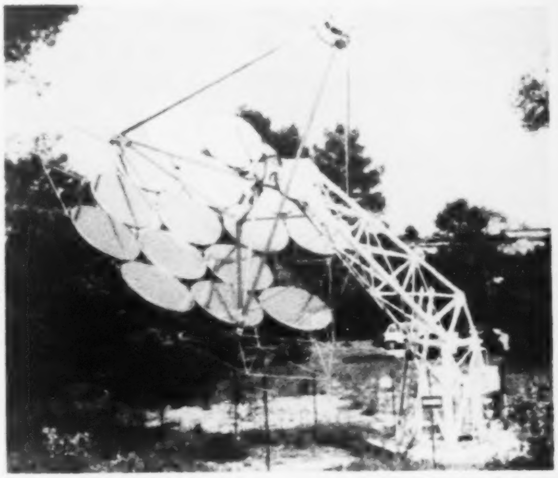

Photo credit: Alan T. Crane

Parabolic dishes focused on a Stirling engine to produce electricity. This assembly was designed and built in the United States and exported to France.

Electric Power Sector

If solar energy is to supply a large fraction of U.S. energy requirements, it will be achieved only with conversion to electricity (with storage) or perhaps hydrogen. Direct applications of solar energy are modest, and most solar technologies lend themselves to electricity generation. Hydroelectric power is the largest renewable energy source and will remain so for many years. Photovoltaics and wind produce electricity directly. Solar thermal and geothermal facilities produce high-grade heat that can be used in several ways, including processing other fuels, but electricity would be the easiest to deliver and use in the foreseeable future. Biomass already fuels a small amount of electrical generation, largely in the forest products industry, and many more opportunities could be created. Hence a commitment to solar implies increased electrification, just as a commitment to nuclear power does in the next scenario.

This scenario projects renewably generated electricity supplies to grow from 3.0 to 11.3 quads by 2015, an increase of 6.8 quads compared to the moderate efficiency scenario. Most of the potential hydropower presently economic or close to it (considering environmental constraints) is developed for an additional 32 GW (yielding 1.5 quads). Biomass for electricity increases 1.7 quads. Solar thermal and photovoltaics together could supply 2.1

quads and wind 2.2 quads. Geothermal increases 0.5 quads. Solar electricity could displace some direct fossil fuel use, but that is not assumed in this scenario. In fact, electricity generation drops 2.9 quads from displacement by the direct use of renewable energy.

Conclusions—The largest uncertainty for the high renewable scenario is whether the technology can be improved sufficiently to provide a reliable, affordable energy source. Only a few renewable technologies are now competitive and most of these only in special situations. Furthermore, as these intermittent sources begin accounting for larger fractions of electricity generation, improved storage will become essential. Cost projections suggest that at least several technologies will be competitive, but that is not yet certain. If the projections prove correct, renewables could grow very rapidly. Some adaptation by individuals and companies might be required to make the most effective use of renewable energy (e.g., revising energy demand profiles to track more closely solar energy availability, and increased installation of backup power equipment). In addition, wide-scale exploitation of renewable energy is likely to cause some conflicts with environmental goals (e.g., farming practices for biomass, aesthetics of solar collectors). Overall, however, if the economics are solved, renewables will follow with considerably less difficulty.

Scenario 6: High Emphasis on Nuclear Power

Twenty-five years ago, the total capacity of all nuclear powerplants in the United States was less than 1200 MWe, about the size of one large modern plant. Today there are over 100,000 MWe in operation, producing almost 20 percent of the power in this country. Over the next 25 years, nuclear power could grow by several hundred thousand MWe, or it could shrink. No domestic energy source except coal has the potential to grow as much in this time interval, but none evokes as much opposition and distrust. The amount of nuclear power capacity that is built in the future depends almost entirely on political decisions and economic factors, but very little on resource constraints or industrial capability (although the latter would be a constraint to very rapid growth).

Table 4-7—High Nuclear Scenario Energy Use and Supply (quadrillion Btu)

	1989	2015
Demand		
Residential		
Natural gas	5.0	3.4
Electricity[a]	3.1	3.4
Oil	1.8	0.8
Coal	0.1	ne
Renewables	0.9	1.5
Total	10.9	9.1
Commercial		
Natural gas	2.7	2.8
Electricity[a]	2.7	3.5
Renewables	ne	0.3
Oil	0.7	0.5
Coal	ne	0.1
Total	6.1	7.2
Transportation		
Oil	21.6	23.4
Natural gas	0.6	0.7
Renewables	ne	0.7
Electricity[a]	ne	0.7
Total	22.2	25.5
Industrial		
Natural gas	8.3	7.2
Oil (fuel)	3.8	4.2
Oil (nonfuel)	4.4	5.7
Electricity[a]	3.2	4.6
Renewables	1.9	3.6
Coal	2.9	3.2
Total	24.5	28.5
Total demand[a]	63.6	70.3
Electricity[b]		
Coal	16.0	12.1
Nuclear	5.7	12.0
Gas	2.9	5.0
Oil	1.7	1.3
Renewables	3.0	7.6
Total	29.2	38.0
Supply		
Oil	34.0	35.9
Gas	19.5	19.1
Coal	18.9	15.4
Nuclear	5.7	12.0
Renewable	5.8	13.7
Total	83.9	96.1

KEY: ne = negligible.

[a] Does not include conversion losses at powerplants, which make up about two-thirds of the total consumed there.

[b] All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

SOURCE: 1989 data—U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, tables 1, 2, 3, 4, 5, 11, 17, 25, 88, and 99; Office of Technology Assessment, 1991.

This scenario assumes that a major commitment to nuclear power is deemed essential, most probably because of global climate change. Table 4-7 shows the energy supply and demand figures. Under this scenario, initial orders are placed by 1994 for updated LWRs, the only proven, commercial nuclear technology. A revival of orders probably would involve a consortium of utilities, manufacturers, and architect-engineers implementing a prelicensed design. Under circumstances leading to high national priority, at least two separate consortia would be likely, each building a reactor of about 600 MWe. These initial reactors would require about 7 years to attain commercial operation, which would be in 2001.

If progress during construction of these test cases is reasonably smooth, subsequent orders might be placed in 2000. Some risk would be involved in ordering before completion of the construction, regulatory, and operational demonstrations, but the situation is not analogous to the premature orders in the sixties and seventies. Now the technology is much more familiar and stabilized. However, utilities are likely to be cautious, so only two more plants (1200 MWe total) are ordered in 2000, and four in 2001. These and following reactors are built on a 5-year construction program.

Alternative technology, in particular the high-temperature gas reactor (HTGR), would be available slightly later, but the net effect on this scenario would be small. Ironically, one of the major advantages suggested of advanced reactors, improved public acceptance, would not apply in this scenario, because public acceptance of conventional reactors is already assumed. However, alternative reactors should still have safety advantages. The type of accident that occurred at Three Mile Island, which entailed serious financial and public relations damage, though releasing only trace amounts of radioactivity, becomes a significant risk if hundreds of LWRs operate for decades. Since this type of accident would again damage the prospects for nuclear power, conversion to more resilient technology probably is necessary at some point. Thus, a high nuclear scenario should include an emphasis on improved technology, even though the risk of a major accident that would harm the public is already much lower than other commonly accepted risks. Rising uranium prices by 2015 may also improve the competitiveness of the liquid metal reactor, but a breeder/plutonium recycle would not be necessary until several hundred GWe have been built.

Table 4-8 shows the progression of orders and commercial operation assumed in this scenario. Reactors are assumed to average 600 MWe each. The rate of starts is low at first, grows rapidly, and then levels out as the number of plants in the construction process becomes large. By 2015, the additional operating capacity is 116,000 MWe and growing rapidly. The existing 103,000 MWe can be expected to decline by about 19,000, for a grand total by 2015 of 200,000 MWe, producing 12 quads. Even faster growth could be envisioned; in 1975, projections called for 1,000,000 GWe in 2000, 10 times what we shall have. However, the rapid growth rate at that time was the source of many of the industry's problems. This more controlled rate should give industry time to acquire qualified workers and build an adequate infrastructure. By 2015, however, the capacity reaches the levels ordered in the early seventies, so the industry may again become strained. In addition to the reactors, several enrichment plants would be required, probably using the laser technology now being developed, which should be cheaper and much more energy efficient than present mass diffusion enrichment technology. At least two high-level waste repositories will also be needed.

Table 4-8—New Nuclear Plant Construction Schedule in High Nuclear Scenario

Year	Plants started in year	Total new starts	Operating capacity (MWe)
2000	2	4	0
2001	4	8	1,200
2002	8	16	1,200
2003	12	28	1,200
2004	16	44	1,200
2005	20	64	2,400
2006	22	86	4,800
2007	24	110	9,600
2008	26	136	16,800
2009	28	164	26,400
2010	30	194	38,400
2011	32	226	51,600
2012	34	260	66,000
2013	36	296	81,600
2014	38	334	98,400
2015	40	374	116,400

SOURCE: Office of Technology Assessment, 1991.

In addition to nuclear, substantial amounts of gas-fired, hydroelectric, and municipal solid waste capacity are built in this scenario. The total capacity by 2015 would be 740,700 MWe. Most coal plants would be retired to reduce CO_2 emissions. Despite the additional energy generated by nuclear reactors, the net output of the electric power sector is only marginally higher than in scenario 3, largely because of the relative inefficiency of nuclear plants.

Relying on nuclear power will change the nature of the energy system, but not as greatly by 2015 as after. This scenario uses nuclear energy more as a means to reduce coal combustion than as an effort to increase electricity production. The use of nuclear reactors to produce industrial process heat has been proposed, particularly using HTGRs, but that is not assumed in this scenario.

The transportation sector will be especially difficult to convert to electricity, because batteries are unlikely to improve sufficiently by 2015 for EV performance to match that of present vehicles. EVs will become widespread after 2000 in this scenario, but the motivation assumed here centers on local environmental benefits rather national efforts to reduce fossil fuel use. Electricity and biomass each supply 0.7 quads in the transportation sector (table 4-7). The biomass component would be more assimilable, but the electricity will power about four times as many vehicles. Alcohol or other biomass fuels must be burned and converted to work at relatively low efficiencies (generally much lower efficiencies than at large, stationary powerplants), whereas the electricity is used directly.

Industry would be unlikely to shift its bulk process heat to electricity because of the cost, unless industrial heat pumps prove effective. Industry will enjoy the greatest benefits from electrification if process redesign exploits electricity's controllability and cleanliness.

Conclusions—Nuclear power will not solve either the CO_2 problem or energy security concerns by 2015, but it can make a major contribution that would grow rapidly thereafter. Before this scenario could be implemented, however, the factors that have immobilized the nuclear option must be addressed. Utilities, their customers, local residents, State rate regulators, investors, and the general public must be convinced that nuclear power in general, and specific proposed plants in particular, are necessary and in their interests.

It is not clear exactly how this consensus would emerge. Global climate change is the issue most likely to improve acceptability. The negative effects that have been suggested for climate change greatly exceed even very pessimistic projections of nuclear accidents. However, the nature of the problems are very different, and people will not necessarily accept a nuclear plant in their area in order to reduce global CO_2 emissions.

This scenario is impossible unless the industry can demonstrate mastery of the technology with existing as well as new plants. Furthermore, a functioning waste repository must be a near-term probability before many new plants are ordered, and proliferation risks must be strictly minimized. In addition, at least initially, nuclear power must be significantly less expensive than renewable options or fossil-fired plants for utilities to consider choosing nuclear.

All of these conditions are possible to meet, but the likelihood of meeting all of them is uncertain. The nuclear industry retains a strong commitment to a revival, but strong policy leadership will be required to convince the rest of the country, at least at first.

Comparative Impact of Scenarios

The six scenarios discussed above are summarized in table 4-9. They represent different assumptions about the problems and opportunities facing the Nation. It would be quite difficult to specify exactly what impact would result from the implementation of any of them, because that would depend on additional assumptions, e.g., regulation of emissions and interest rates. Furthermore, the value of scenarios 4, 5, and 6 depends to a large extent on how crucial it becomes to reduce CO_2 emissions, which cannot be determined at this time. However, major types of impacts can be identified.

The three major parameters for the design of the scenarios were: 1) how to minimize environmental impacts, especially global warming; 2) how to minimize vulnerability to energy disruptions; and 3) how to minimize economic costs to society. Success in meeting these three goals, assuming the scenarios are implemented successfully, is the first type of impact to be considered. This has been discussed for each scenario above. As summarized in table 4-10, the high growth scenario worsens environmental and security impacts relative to the base scenario and leaves economic impacts about the same, largely because of the assumption that the scenario is improbable unless fuel prices stay lower than assumed in the other scenarios. The remaining scenarios reduce environmental impact and security risks. The moderate efficiency scenario shows a strong positive economic impact because it is the least-cost path. High efficiency and high nuclear should not cost much more than the base scenario

Table 4-9—Summary of Scenarios

	1989	2015 Baseline	2015 High Growth	2015 Moderate Efficiency	2015 High Efficiency	2015 High Renewable	2015 High Nuclear
Demand							
Residential							
Natural gas	5.0	4.2	5.5	3.6	2.9	3.3	3.4
Electricity[a]	3.1	4.0	4.8	3.3	2.6	2.8	3.4
Oil	1.8	1.1	1.3	0.9	0.8	0.7	0.8
Coal	0.1	0.1	0.1	0.1	ne	ne	ne
Renewables	0.9	1.5	1.5	1.2	0.6	2.3	1.5
Total	10.9	10.9	13.2	9.1	6.9	9.1	9.1
Commercial							
Natural gas	2.7	3.4	3.6	3.0	3.8	2.7	2.8
Electricity[a]	2.7	5.2	5.5	3.4	1.7	3.0	3.5
Renewables	ne	ne	ne	ne	ne	0.9	0.3
Oil	0.7	0.9	0.9	0.7	0.3	0.5	0.5
Coal	ne	0.1	0.1	0.1	0.1	0.1	0.1
Total	6.1	9.6	10.1	7.2	5.9	7.2	7.2
Transportation							
Oil	21.6	27.5	32.6	24.8	17.7	23.6	23.4
Natural gas	0.6	0.7	1.5	0.7	0.7	0.7	0.7
Renewables	ne	ne	0.5	ne	ne	1.2	0.7
Electricity[a]	ne	ne	0.7	ne	0.1	ne	0.7
Total	22.2	28.2	35.3	25.5	18.5	25.5	25.5
Industrial							
Natural gas	8.3	7.7	10.9	7.5	7.7	6.7	7.2
Oil—fuel	3.8	5.0	5.6	4.4	3.3	3.7	4.2
Oil—non-fuel	4.4	5.7	6.5	5.7	5.7	5.7	5.7
Electricity[a]	3.2	5.3	6.4	4.4	3.2	4.4	4.6
Renewables	1.9	3.5	3.8	3.2	2.2	4.8	3.6
Coal	2.9	4.6	5.3	3.3	1.5	3.2	3.2
Total	24.5	31.8	38.5	28.5	23.6	28.5	28.5
Total demand[a]	63.7	80.5	97.1	70.3	54.9	70.3	70.3
Electricity[b]							
Coal	16.0	29.1	27.4	17.8	5.3	12.1	12.1
Nuclear	5.7	3.8	8.2	6.6	6.8	4.3	12.0
Gas	2.9	6.3	7.0	4.1	5.3	2.7	5.0
Oil	1.7	1.6	1.6	1.5	0.2	1.2	1.3
Renewables	3.0	5.7	5.5	4.5	5.2	11.3	7.6
Total	29.2	46.4	49.7	34.5	22.8	31.6	38.0
Supply							
Oil	34.0	41.8	48.5	37.9	27.8	35.3	35.9
Gas	19.5	22.3	28.5	18.8	20.3	16.0	19.1
Coal	18.9	33.8	32.9	21.1	7.0	15.4	15.4
Nuclear	5.7	3.8	8.2	6.6	6.8	4.3	12.0
Renewable	5.8	10.7	11.3	8.9	8.0	20.5	13.7
Total	83.9	112.4	129.4	93.3	70.0	91.5	96.1

KEY: ne = negligible.

[a] Does not include transmission and disribution losses nor conversion losses at powerplants, which is about two-thirds of the total consumed there.

[b] All fuel used for power, with hydroelectric and other nonthermal powerplants artificially rated at average thermal efficiency.

SOURCE: Reference for 1989 data—U.S. Energy Information Administration, *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, tablels 1, 2, 3, 4, 5, 11, 17, 25, 88, and 99; Office of Technology Assessment, 1991.

because they use relatively familiar technology that is competitive or nearly so now. Renewable costs presently are higher, and projections of reductions are somewhat speculative.

However, other factors will be crucial in determining the national impacts of committing to one or another scenario. Some scenarios involve considerable uncertainty regarding resource availability or technical progress, and some introduce additional uncertainties for unpredictable events, e.g., nuclear accidents or major climatic events that reduce solar energy significantly. Resilience of the scenarios to

Table 4-10—Comparative Impact of Scenarios

Impact	Base	High Growth	Efficiency	High Efficiency	Renewable	Nuclear
Environmental	0	– –	+	++	++	+
Security	0	–	+	++	++	++
Economic	0	0	++	0	–	0
Resilience	0	– –	+	++	+	0
Implementability						
Infrastructure	0	++	–	– –	–	+
Public acceptance	0	0	+	–	+	–
Sustainability	0	– –	+	++	++	+

KEY: 0 = about the same as the base case; + = somewhat better or easier; ++ = much better; – = somewhat worse or harder; – – = much worse.

SOURCE: Office of Technology Assessment, 1991.

uncertainties includes both the probability of success and the consequences of failure and depends in part on the technologies involved. The high growth scenario has particularly uncertain assumptions. The high efficiency scenario is most immune against negative surprises and vulnerable principally to improbably low energy prices.

The ability to implement any of the scenarios depends on several factors. Public acceptance is one consideration. Some technologies (e.g., solar) are quite popular with the public (in the abstract), and promotional policies are likely to be widely supported. Conversely, the level of public involvement required to implement these technologies may be high, which increases the difficulty of implementation. Demand-side measures in particular require people to focus on energy decisions (purchasing and operating equipment) more than has been experienced to date. Some solar options also involve users more intensively than does the purchase of conventional energy. Industrial readiness to implement the scenarios also varies. The fossil and nuclear industries already exist. The solar and conservation industries would have to expand greatly.

Finally, there is every reason to believe that in the next century, U.S. energy supplies will have to shift from fossil fuels toward a more sustainable system. Significant changes to the energy system can take decades to accomplish, but some scenarios would make these changes faster and more efficiently than others.

Some factors are not considered here because they are too complex. In particular, employment under the different scenarios will vary in numbers, types of jobs, and geographic location. One of the most notable shifts would be the decrease in coal field employment under scenarios 4, 5, and 6. Compensating increases could be found elsewhere, but they are unlikely to help the coal miners or their regions. Nor are changes in energy demand and supply due to global warming (other than those changes deliberately implemented out of concern over climate change) considered here, even though such warming could be detectable (though probably not large) by 2015 under scenarios 1 and 2.

Table 4-9 evaluates these factors qualitatively relative to the base scenario. The scores cannot be averaged to determine totals because the six factors listed do not represent all important considerations, nor would they be equally weighted. However, it does appear that scenario 3, moderate conservation, has most of the advantages and few of the disadvantages of the others.

Overall, it is clear that no one subset of energy technologies is going to solve all the problems the Nation will have to confront eventually. Each scenario has drawbacks as well as advantages, and different circumstances could invalidate any of them. We do not know: how much of the Nation's huge unconventional gas resources can be developed at reasonable cost; what technology breakthroughs will change the relative economics of the various energy sources; what new sources of demand will emerge; how serious global warming will be; or what external events will occur to change the way we think about energy.

Furthermore, if the Nation decides that global warming is a serious problem, then even the interim goal of a reduction of 20 percent in CO_2 emissions will be much too small. Even 50 percent could be modest under some conditions, but such a goal could only be achieved by strenuously combining scenarios 4, 5, and 6.

This argues strongly for assuring that a wide range of technologies is available in the future, and that no option be discarded prematurely.

Chapter 5

Policy Issues

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Chapter 5

Policy Issues

INTRODUCTION

The previous chapter describes six alternative views of the Nation's energy future presented as divergent scenarios of U.S. energy supply and demand by 2015. This chapter explores policy issues concerning each of these energy futures. The options are considered as they relate to the three major goals behind energy policy discussed in chapter 1—economic competitiveness, environmental health, and energy security. These three goals are also recognized as preeminent in the President's National Energy Strategy (NES).[1]

As mentioned earlier, the scenarios in this report are not predictions. Their purpose is to convey outcomes for six alternative energy futures based on varying assumptions about the implementation of differing technologies that could affect energy supply and demand by 2015. This chapter is not meant as a general description of energy policy nor as a quantitative assessment of policy options. With few exceptions, the scenarios are developed without a priori assumptions about the exact nature and extent of policies used to attain the technological implementation assumed in each. Those decisions are left to policymakers and are not directly relevant to conveying the technological promise theoretically possible under each scenario.

Only the first case, the base scenario, could be implemented without altering existing Federal statutory and regulatory policies. The other scenarios, to varying degrees, draw on the following categories of policy initiatives: standards; financial mechanisms; energy taxes; information management; research, development, and demonstration programs; and Federal programs.

Standards can be designed to promote energy efficiency, pollution reduction, or improvements in energy-using behavior. Automobile fuel economy, appliance efficiency, pollution control, and building code standards can improve the energy performance of new equipment or processes and can eliminate the manufacture or construction of the least efficient equipment or stock in the marketplace.

Although not typically conceived as such, pollution limits have the potential to save energy as well. If properly designed, pollution standards can encourage manufacturers, utilities, and consumers to increase their level of goods or services per unit of energy consumed, or per unit of emissions generated. For example, pollution standards that encourage the use of industrial wastes as feedstock or the implementation of cogeneration systems would lead to direct gains in energy efficiency.

Along with efficiency and pollution standards, a third type of requirement can induce energy-savings through behavior modification. For example, a mandated national speed limit of 55 miles per hour (mph) would slow average highway speeds and save a considerable amount of energy in transport.[2]

Financial mechanisms can increase the competitiveness of energy efficient measures, technologies, or fuels not otherwise economical or preferred by consumers. Financial mechanisms include incentives such as tax credits, low-cost loans, or direct payments by Government or, in the last two instances, by utilities. Financial mechanisms can establish a level field for competing goods or services by eliminating indirect subsidies that discourage energy conservation or by creating subsidies that encourage energy conservation. For example, consumer appliance efficiency rebate programs can spur energy-saving retrofits while reducing utility load requirements.

Other kinds of financial mechanisms use the market directly to improve energy use, e.g., tradable emissions permits. Tradable permits have been authorized under the U.S. Clean Air Act (CAA) to reduce emissions of sulfur dioxide (SO_2) at coal-fired electricity generating plants, and the concept could be extended to carbon emissions. By enabling firms to profit from exceptional emissions reductions, tradable permit systems provide an incentive for polluting industries to reduce emissions beyond mandated standards, which by themselves offer no benefit or incentive for polluters to surpass once they are in compliance.

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[1] *National Energy Strategy: Powerful Ideas for America*, 1st ed. 1991/1992 (Washington, DC: U.S. Government Printing Office, February 1991).

[2] A 1985 study on the effect of vehicle speeds on automobile fuel consumption found that the average fuel economy loss of tested vehicles was about 18 percent when average speed increased from 55 to 65 mph. See Stacy C. Davis and Patricia S. Hu, *Transportation Energy Data Book: Edition 11*, ORNL-6649 (Oak Ridge, TN: Oak Ridge National Laboratory, January 1991), p. 3-68.

With the tradable permit system created under the CAA, utilities have been given a strong incentive to increase their energy production per unit of SO_2 emissions as a means of generating additional profit. Technologies now or nearly available, e.g., integrated gasification combined cycle (IGCC) and steam-injected gas turbines (STIG), offer both low emissions and high efficiency, and they may become more widespread as the new provisions of the CAA are implemented.

Thus, appropriately designed incentives could guarantee that energy efficiency becomes an integral rather than confounding feature in efforts to reduce emissions. Marketable emissions permits for carbon dioxide (CO_2) in the industrial and utility sectors would be even more useful than those for sulfur in promoting energy savings.

Energy taxes have the potential, if set high enough, to reduce energy consumption and petroleum imports, while encouraging investments in energy efficient equipment and technologies. Energy taxes may apply directly to energy purchases, e.g., gasoline taxes, or they may apply to the initial purchase of energy-using equipment, e.g., gas guzzler taxes for the least efficient vehicles in the new light-duty fleet market. A currently discussed alternative, a tax based on carbon emissions, would also improve the competitiveness of renewable and nuclear technologies, while reducing CO_2 emissions.

A disadvantage of energy taxes is that they are generally regressive, burdening lower income groups disproportionately. In the short term at least, energy taxes would reduce some economic activity and have an inflationary impact on the economy. These effects would be partially offset by a growth in energy efficient technologies and services. The general economic effects of energy taxes, however, would shrink as the economy became less energy intense in response to the price increases brought on by taxes. Finally, energy taxes would directly increase Treasury revenues and reduce the Federal deficit, but these benefits would be indirectly offset to some degree by reduced economic activity, at least in the short term, which would lower Federal tax revenues from other sources.

Information management—in the form of public or professional education, training, workshops, information dissemination, or program evaluation—educates consumers and professionals about options to improve energy efficiency and conservation practices.

Research, development, and demonstration (RD&D) programs develop new options or advance current options toward commercial availability. The last element, demonstration, can be vital, because research and development (R&D) programs often fail to demonstrate the practical applications of new or improved technologies or fail to improve the prospects of their commercial availability.

Promising energy technology R&D projects are shown in tables 2-1 and 3-1. Budget increases will be needed for many of these technologies to achieve widespread commercial availability. Reversing the drastic cuts in U.S. Department of Energy (DOE) R&D conservation budgets that began in 1982 would be an important step to improving the commercial prospects of these technologies (figure 5-1).

Federal programs can increase energy conservation and efficiency in the Government and other sectors or increase energy supplies. A recent OTA report describes in detail the progress and prospects of improving Federal Government energy efficiency.[3] In addition to lowering Federal and State energy costs, Government programs can help new or experimental energy technologies reach the marketplace. Additionally, Federal efforts to push exports of domestically manufactured energy efficient technologies can improve their economies of scale in production, with the prospect of expanding the markets for these goods both domestically and internationally.

On the supply side, Federal policies determine areas available for oil, natural gas, renewable, and other supply source exploration and development. This category includes decisions about whether new areas, e.g., the Alaska National Wildlife Refuge,

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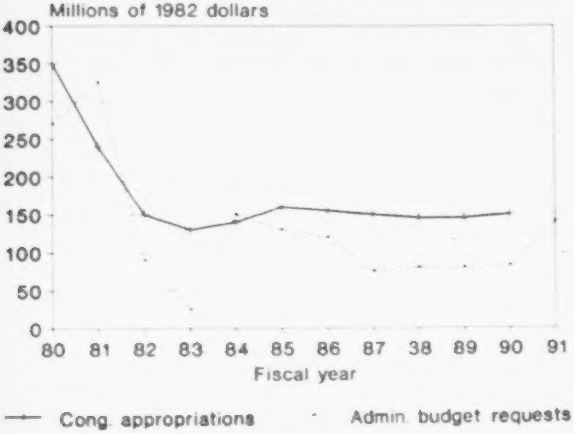
[3] U.S. Congress, Office of Technology Assessment, *Energy Efficiency in the Federal Government: Government by Good Example?* OTA-E-492 (Washington, DC: U.S. Government Printing Office, May 1991).

Figure 5-1—DOE Conservation R&D Budgets, Budget Requests, and Appropriations



SOURCE: U.S. General Accounting Office, *Energy R&D—Conservation Planning and Management Should Be Strengthened*, GAO/RCED-90-195, July 1990.

should be open to development. Federal programs also include the Strategic Petroleum Reserve (SPR).

At varying levels of implementation, these policy options are discussed below for the six scenarios given in this report. Each scenario covers the period 1989-2015.

BASELINE SCENARIO

The first scenario assumes that no major new energy-related policy initiatives are undertaken. In this scenario, fossil fuels remain the cheapest available energy source, and they continue to drive the economy. Total energy consumption climbs almost 1 percent per year, reaching 112.4 quads (quadrillion British thermal units) in 2015.

The baseline scenario is not meant to suggest that no energy policy changes will be implemented during the period 1989-2015. As national and international developments occur in this period, energy-related policy changes are likely to follow. The recent Gulf War suggests how quickly attention to energy policy is revived. Moreover, energy legislation proposed in the 102d Congress—including the proposed NES—promises to alter national energy policy in the near term. For the purposes of this scenario, however, we assume no changes that would significantly alter the framework under which energy decisionmaking takes place today.

Even without major policy changes, some energy efficiency improvements are expected. Under the conditions described in chapter 4, this scenario predicts modest efficiency improvements by 2015 through normal upgrading and equipment turnover. Use of available shell improvements will allow the 35 million new homes and apartments projected to be built between 1995 and 2015 to require 15-percent less heat and 8-percent less air conditioning than current new homes. Without changing current Federal fuel economy standards, new cars are projected to average 36.5 miles per gallon (mpg) by 2010. The appliance efficiency standards under the National Appliance Energy Conservation Amendments of 1988 (NAECA), Public Law 100-12, are assumed to remain in effect as well.

Under this scenario, U.S. oil import dependence would reach unprecedented levels, about two-thirds of consumption by 2015.[4] The prospects of climate change would worsen as well, and urban air quality would remain poor from continued transportation energy growth.

HIGH GROWTH SCENARIO

Government policies in this scenario focus on expanding supply rather than on diminishing demand to fuel a period of high economic growth. The high growth scenario envisions total U.S. energy demand rising to 127 quads by 2015, a growth rate of about 1.7 percent annually. Energy demand in this scenario exceeds that of the base scenario for all sectors. Like the base scenario, this scenario requires a plentiful supply of relatively cheap fossil energy during a period that introduces no major new environmental constraints that might induce controls on energy demand.

To meet the supply projections under the high growth scenario, coal, natural gas, and nuclear energy would all have to be expanded significantly. Efforts to bolster domestic oil production would also be necessary to keep domestic production from dropping too sharply by 2015. Policies would have to encourage increased domestic production of these sources, while protecting against supply disruptions to prevent shortages and drastic energy price rises.

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[4] Recent U.S. Department of Energy (DOE) projections of U.S. petroleum import dependence suggest that foreign sources could represent over two-thirds of U.S. supplies by 2010 under their reference (base) case. The DOE reference case assumes nearly the same level of economic growth (2.1 percent) used here (2.3 percent). *Annual Energy Outlook 1991: With Projections to 2010*, DOE/EIA-0383(91) (Washington, DC: U.S. Government Printing Office, March 1991), pp. 3, 43.

The options to expand supply in this scenario echo the proposed NES. For example, the development and use of advanced oil recovery technology to extract currently unrecoverable domestic reserves in the range of 300 billion barrels would be important. Also, increasing exploration in offshore and other unexplored areas, such as the Alaska National Wildlife Refuge, would help meet the supply projections in this scenario. To expand domestic supply exploration and development, a variety of environmental concerns would have to be addressed, but they could not raise the cost of the final products by much or they would not be competitive under this low-price scenario.

If coal is to be used in the quantities assumed here, stricter SO_2 and nitrogen oxide (NO_x) emissions controls may be necessary to avoid violating air quality standards. Though coal remains abundant and cheap under this scenario, tighter emissions standards could not raise the price of energy significantly, or the low-price, high-growth conditions of this scenario would be compromised, and prices would rise and demand would shrink accordingly. Thus, expanding Government support for RD&D to improve combustion (e.g., fluidized bed or gasification in combined cycle plants) would help enhance generating efficiency while offsetting the emissions increases that are a major feature of this scenario. In addition, a tradable emissions permit system (broader in scope than that created under the Clean Air Act Amendments of 1990) could stimulate technological improvements in emissions control for coal burning or motivate an increase in the energy intensity of electricity generation beyond the levels expected under current legislation.

Heavy reliance on fossil fuels will negatively affect urban air quality (particularly in carbon monoxide and ozone nonattainment areas).[5] In response, this scenario assumes that the use of electric vehicles (EVs) becomes more widespread, which would require Government incentives to induce manufacturers to produce such vehicles on a larger scale. This option is an element of the NES, and some areas (e.g., California) are already beginning to incorporate EVs in their environmental and transportation planning. However, EVs are expensive and suffer from poor performance. Government RD&D and incentives are likely to be required if they are to be important contributors to urban air improvement in the short to medium term.[6]

To maintain low electricity prices, increasing competition could be vital. Changes to the Public Utility Holding Company Act of 1935 (PUHCA) could ease the financial and other constraints on utilities that service customers in more than one State. Though amending PUHCA could have a generally positive effect on competition, the full effects of any PUHCA changes need to be understood before major amendments are made to prevent either small or large generators from enjoying undue competitive advantages or disadvantages.

The large diversion of coal (one-third of production) to synthetic fuel production under the modest price rises assumed for oil and natural gas in this scenario is not probable absent price incentives and expanded RD&D, both of which the Government would have to provide. Concerns about rising levels of petroleum imports, which are assumed in this scenario and likely in any event, would be the likely impetus for synthetic fuel production of this magnitude.

To expand domestic natural gas supplies, increased RD&D for gas recovery in tight sand and other unconventional formations would be necessary to exploit the greater part of U.S. reserves at reasonable cost. As noted in chapter 4, this scenario is largely contingent on the increased supply of relatively cheap natural gas and, without government help, domestic natural gas production is likely to be waning by 2015, because the price assumptions used in this scenario would be insufficient to spur natural gas exploration at the levels projected here. As proposed, the NES supports R&D to improve natural gas production, as well as regulatory reform to prevent delays in building new pipeline capacity. Both of these steps would be important in this scenario.

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[5] For the period 1987-89, the U.S. Environmental Protection Agency (EPA) determined that 96 areas (mostly major metropolitan areas) failed to meet the Federal ozone standard, and 41 areas failed to meet the Federal carbon monoxide (CO) standard in the period 1988-89. The total population in the areas violating these health-based standards was an estimated 66.7 million in 1989 for the ozone areas alone. Furthermore, the connection between these areas and transportation emissions is strong; in 1989, 65 percent of national CO emissions were from transportation sources, while 35 percent of national volatile organic compound emissions, the precursors of ground-level ozone formation, were from transportation sources. U.S. Environmental Protection Agency, *National Air Quality and Emissions Trends Report, 1989*, EPA-450/4-91-003, February 1991, pp. 3-17, 3-27, 4-1, 4-5.

[6] A detailed assessment of the prospects for increasing the use of alternative fuels in the transportation sector is found in U.S. Congress, Office of Technology Assessment, *Replacing Gasoline: Alternative Fuels for Light-Duty Vehicles*, OTA-E-364 (Washington, DC: U.S. Government Printing Office, September 1990).

Additional RD&D for enhanced oil recovery in existing fields may be required, as well as improved exploration and drilling techniques, especially off-shore. Increasing both imports and domestic production also suggests that improved safeguards against oil spills would be necessary. To reduce the potential for oil supply and price disruptions under the high growth scenario, exploiting protected areas in Alaska and off-shore would help prevent domestic oil production from diminishing too quickly. Even with expanded exploration of this kind, however, domestic oil production is expected to continue declining. For further protection against supply or price disruptions, the SPR would have to be enlarged.

To expand nuclear power, attention to RD&D, regulatory treatment, waste disposal, and decommissioning would be necessary, as well as a visible effort by the Government to restore public confidence in the industry. Standardizing designs and simplifying licensing are crucial ingredients for a revival. Preapproval of designs, and perhaps sites, might be possible. However, it could be very damaging to public acceptance if a streamlined licensing process is viewed as steamrolling opposition. Along with an improved regulatory environment, the nuclear industry itself would require improvement in financial and facility performance for nuclear power to expand to the 70,000 megawatts (MW) by 2015 assumed here.

Part of the effort to restore the credibility needed for the nuclear industry to gain wider public support will require faster progress on a waste disposal facility. OTA believes that the construction of new nuclear facilities will be limited until major progress toward an operable waste disposal facility is visible. In addition, public acceptance of expanded nuclear power is not likely to improve as long as the availability of cost-effective efficiency improvements remains great. Suggestions in the proposed National Energy Strategy to improve the acceptance and use of nuclear power fail to indicate how to address potential public concern about nuclear growth at a time when many options to implement cost-effective demand control are available.

The nuclear R&D program has been declining since the cancellation of the Clinch River Breeder Reactor in 1983. Increased RD&D for alternative reactor designs and processes could lead to technology that could more easily recapture public trust.

MODERATE EFFICIENCY SCENARIO

Improved efficiency has been the major energy success story since the first oil crisis in 1973. Had the pre-1973 trends in the growth of U.S. energy consumption continued unabated, total energy use here would have been 32 quads higher in 1986 than the actual 72 quads consumed that year. For the period 1973-86, this resulted in a cumulative savings totaling 171 quads, valued at over $950 billion (1986 dollars).[7] Despite these large gains, there are vast opportunities for further improvements.

In contrast to the previous scenario, therefore, the focus of the moderate efficiency scenario switches from increasing energy supply to reducing energy demand. As noted in chapter 4, this scenario assumes that available cost-effective, energy-savings opportunities are fully exploited due to direct policy intervention.[8] While this optimal level of cost-effective investment would theoretically benefit consumers and the Nation as a whole, it would be unprecedented, requiring the elimination or reduction of significant market, institutional, and behavioral barriers that prevent the full use of currently available cost-effective energy-savings opportunities.

A combination of policy options (energy taxes, standards, financial mechanisms, information programs, RD&D) would best serve the efficiency targets in this scenario, because each exerts unique effects in overcoming the barriers to optimal energy efficiency and conservation actions. The NES advocates strongly only the last three options, while postponing or dismissing consideration of revising standards or broadening energy taxes. Nonetheless, a significant, broad-based energy tax is perhaps the single most effective means of improving efficiency in this or other scenarios. A gasoline tax in the range of $0.50 per gallon, with equivalent increases for other energy sources, would have a major impact on how consumers make energy-related decisions. For example, a recent OTA report suggested that a sustained increase in gasoline prices of 50 percent could lessen gasoline demand 8 percent (between 5 and 20 percent),[9] but the gasoline price elasticity assumed in this estimate is an extrapolation of empirical data. In other words, estimating gasoline price elasticity at such high prices is uncertain, because the United States has not experienced sustained gasoline price rises (in real terms) of this magnitude.

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[7] U.S. Department of Energy, *Energy Conservation Trends: Understanding the Factors That Affect Conservation Gains in the U.S. Economy*, DOE/PE-0092 September 1989, p. 5; and *Annual Energy Review 1989*, DOE/EIA-0384(89), May 24, 1990, p. 7.

[8] This maximum number is based on the energy price projections noted in ch. 4, and it considers only investments that yield net positive economic benefits when amortized over expected equipment life.

Across the board energy taxes would increase the level of energy efficient construction and manufacturing for residential and commercial stock, vehicles, appliances, and other equipment. In the industrial sector, energy taxes could motivate the wider adoption of adjustable-speed drive (ASD) and other motor efficiency improvements to save 10 percent of the energy projected for use by motors in the base scenario in 2015. Of course, taxes would have to be high enough to motivate improvements but low enough to allow consumers sufficient investment capital to afford such equipment and conservation measures.

Energy taxes could also be applied to the initial purchase of energy-using equipment. These taxes could be scaled in a way that would raise the cost of the least efficient equipment the most in order to produce a level field for similar products in consumer markets. Taxes on carbon emissions or imported oil would have similar but more selective results. These taxes could be justified as efforts to capture the environmental and social externalities of providing energy or they could be levied in an effort to reduce the Federal deficit. Raising prices through energy taxes to capture these externalities would be consonant with the combination of economic, environmental, and energy security goals outlined in chapter 1.

Of course, there are social costs to raising energy taxes significantly. In particular, energy taxes would be regressive; lower income individuals and families would experience a greater marginal burden if such taxes were imposed, because energy costs consistently account for a higher fraction of income in low-income households.[10] This report does not analyze social equity issues such as this. It merely notes that one of the most efficient ways to induce effective energy-saving decisions is to raise the cost of energy.

Barriers to maximizing cost-effective, energy-saving investments are not merely price-oriented. Reliable information on energy-saving opportunities needs to increase in all sectors. Most people, for instance, are aware that measures such as insulating residences or driving high mileage cars will save energy, but few are aware of the full range of investments that can profitably save money by saving energy. Information programs such as appliance labeling can be useful, but only if consumers are aware of them and understand them. The scope and clarity of Federal energy information programs could increase to assure consistent and meaningful information for appliances, building energy rating systems, and other energy-using equipment or stock.

Passive programs that simply supply some information, or supply information only when asked, will not reach a high proportion of consumers. Other actors that can aid or influence consumer decisions about energy use—builders, lenders, landlords, manufacturers, utilities, and the media—should participate to ensure that appropriate decisions about energy use are made. The assumed level of building retrofits in this scenario implies a key role for information programs, because the first step in retrofitting programs is generally informational.

Buildings, vehicles, and appliances possess a wide range of energy efficiencies. Stringent standards can eliminate the least efficient. Moreover, standards would correct a problem unique to buildings: many decisions about investing in energy efficient design are made by builders and landlords, rather than subsequent buyers or renters. Unlike appliances and vehicles, the decision about whether to invest in energy efficient building design is made for the consumer in advance. Standards would help correct this basic problem.

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[9] Office of Technology Assessment, *Changing By Degrees: Steps To Reduce Greenhouse Gases*, OTA-O-482 (Washington, DC: U.S. Government Printing Office, February 1991), p. 165.

[10] For example, in 1984, low-income households (below $5,000) that used automobiles spent about $770 (15 percent) per year for motor fuel on average. Households earning more than $25,000 per year spent about $1,140 for motor fuel, or less than 5 percent of income on average. U.S. Department of Energy, "Energy Security: A Report to the President of the United States," DOE/S-0057, March 1987, p. E-6.

In the moderate efficiency scenario, standards could be raised significantly in all sectors and still meet the criterion of life-cycle paybacks used in this scenario. The NAECA standards, for example, could be strengthened; at present, the method for revising these standards may effectively encourage the widespread use of three-year payback periods,[11] but the opportunity for efficiency gains typically increase when longer paybacks are used in setting standards. To be sure, there is *no* current requirement under NAECA to set standards at levels that would ensure paybacks strictly determined on a life-cycle basis.

Mandatory Federal building standards are currently restricted to Federal buildings, and they are not enforced strictly. Under this scenario, these standards could be strengthened to require high, but still cost-effective, efficiency levels, expanded to include residential and commercial structures, and enforced. State energy grants disbursed through the Federal State Energy Conservation Program (SECP) and other DOE and U.S. Department of Housing and Urban Development (HUD) programs could be restricted to States that have adopted the national Building Energy Performance Standards (BEPS) or other building codes, such as the Council of American Building Officials "Model Energy Code" (CABO "MEC"). One way to bolster enforcement programs is to attach major fines for noncompliance or encourage States and localities to deny occupancy permits to new buildings failing to meet efficient design requirements. Even if strictly voluntary, an aggressively promoted Federal standards program for buildings could dramatically improve energy efficiency in new residential and commercial structures.

Arguably, increasing energy prices might be more economically efficient in improving energy use in buildings compared to setting rigid standards for efficiency performance. However, estimating the effects between taxes and standards in the buildings sector is complicated by the diversity and uses of building types. Comparing the effects of taxes and standards for vehicles, on the other hand, is less complicated. Meeting the fuel economy targets given in this scenario might be achieved most efficiently through energy taxes, but experience in other industrialized nations suggests that such a tax would have to be high, as much as two to three times the current U.S. price.

Strengthening fuel economy standards directly is an alternative approach to taxes that appears to have been effective in the United States with lower cost to consumers. However, raising prices through energy tax increases would affect *all* vehicles, not just new ones. Raising energy prices and strengthening fuel economy standards together would encourage the scrappage of older, less efficient vehicles at a time when new vehicle fuel economy was rising. The effect would be to raise the efficiency of the entire fleet much more quickly than we have experienced in the United States with just new vehicle standards working by themselves.

In fact, fuel economy standards in this scenario would not need to increase much over levels expected in the base scenario to achieve significant energy savings. Year 2015 new auto fuel efficiency of 39 mpg and new light truck efficiency of 35.5 mpg could be achieved if regulations raised the fuel economy of these vehicles only about 10 percent above that already predicted by the base scenario where no regulatory changes occur. Along with reinstating the 55-mph speed limit, improving traffic flow in urban areas, and several other measures, growth in transportation energy use could be halved relative to the base scenario if existing vehicle efficiency standards were raised to the levels suggested above. While small increases in vehicle standards would not eliminate gas guzzlers, which tend to be the most expensive personal passenger vehicles, they would raise the fleet average.

The additional purchase cost (also known as first cost) of energy efficiency measures commonly prevents firms or individuals from acquiring them. Financial mechanisms could soften or eliminate the first cost barrier. Tax credits applied, for example, to efficiency investments, conservation measures, or both could be set at minimal losses to the Federal Treasury while helping to reduce the flow of oil imports. Moreover, revenues lost from Federal tax and other incentive programs could be offset by increasing energy taxes to achieve no net effect on Government revenues.

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[11] "If the [DOE] Secretary finds that the additional cost to the consumer of purchasing a product complying with an energy conservation standard level will be less than three times the value of the energy savings during the first year that the consumer will receive as a result of the standard, as calculated under the applicable test procedure, there shall be a rebuttable presumption that such standard level is economically justified. A determination by the Secretary that such criterion is not met shall not be taken into consideration in the Secretary's determination of whether a standard is economically justified."—42 U.S.C. 6295(l)(2)(B)(iii). There are varying interpretations of how this requirement for determining economic justification will play out but, under the conditions of the moderate efficiency scenario, this requirement would have to be strengthened to meet the condition of exploiting all life-cycle payback opportunities.

Tax credits could also be applied to equipment using renewable energy sources (solar, wind, geothermal). The Federal Government has experience with both types of credits in the residential, commercial, and industrial sectors, particularly under the Energy Tax Act of 1978 (ETA), Public Law 95-618, and the Windfall Profits Tax Act of 1980 (WPTA), Public Law 96-223. Tax credits would lower Federal Treasury revenues directly, but they would indirectly raise some of these revenues by stimulating economic activity that might not otherwise have occurred but for the incentives.

The marginal benefits that tax credits actually provided the industrial sector under the WPTA was uncertain, because many firms may have made their efficiency investments regardless. Other mechanisms, e.g., low-cost loans and direct payments, might be targeted and administered more effectively by States and utilities, as they can often evaluate better fuel use, load, and cost changes in balance with projected demand and supply growth, but the Federal Government could go far to ensure that such programs are created and reach a wide audience.

Accelerated capital depreciation is also a financial mechanism that has been cited as an option to encourage investment in new equipment. The effect of accelerated depreciation can be mixed, however. By reducing the period in which businesses can write off investments, companies lower their tax bills, presumably leaving more for investment, but U.S. Treasury receipts are lowered as well.[12]

A vigorous RD&D program could accelerate the commercialization of new or emerging efficiency technologies. Most of the options listed in table 2-1 would improve efficiency. For example, compact fluorescent light bulbs are economical under some conditions but are too costly and bulky for widespread application. As these problems are solved, more of these bulbs should become interchangeable with incandescents. Most efficiency RD&D programs could be usefully increased, which would improve the chances of implementing this scenario even though existing technology is nominally sufficient.

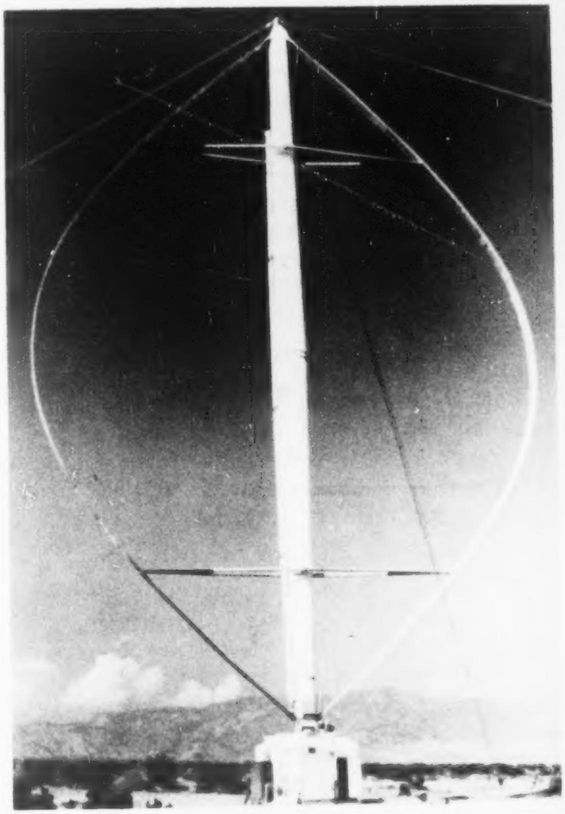

Photo credit: Southern California Edison Co.

A 500-kW wind turbine mounted on a vertical axis in California.

Many of the policy measures noted here could also be valuable on the supply side. In particular, energy taxes, regulatory changes, financial mechanisms, or some combination of them could expand the fossil and nonfossil supply base. Any of these mechanisms could be used singly or in combination to meet the moderate growth in energy supply assumed in this scenario. These tools could be used singly or in combination to expand the contribution of renewable sources of energy, which are assumed to cover 40 percent of new electricity demand by 2010. In addition, these tools could achieve the extensive use (70 percent) of cogeneration in new and replacement industrial steam boilers by 2015.

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[12] A more detailed discussion of the history and role of financial incentives in the U.S. industrial sector can be found in U.S. Congress, Office of Technology Assessment, *Industrial Energy Use*, OTA-E-198 (Washington, DC: U.S. Government Printing Office, June 1983), pp. 56-58.

Federal energy use could be improved through mandatory building, equipment, and fleet efficiency standards; retrofitting existing shells and lighting systems; and participating in local utility demand-side management efforts. Furthermore, committed Federal efforts to invest in cost-effective energy efficiency technology through serious procurement efforts would be essential to bolster Federal credibility if major national programs are created to reduce U.S. energy use. Federal legislation or executive orders may be well-intentioned but have experienced poor results historically. To ensure that such efforts attain their desired results, financial support, enforceable provisions, appropriations contingencies, or some combination of these could be used to achieve Government efficiency and conservation improvements that maximize cost-effective options. Revisions to Federal procurement and leasing guidelines and requirements could also promote new demand- and supply-side technologies.

There are three general reasons for pursuing energy savings through some or all of these policies. First, maximizing cost-effective energy savings reduces the cost to produce U.S. goods and services in the domestic and international markets, thereby making those goods and services more competitive. Second, energy savings under this scenario would dampen U.S. reliance on imported petroleum.

Finally, energy savings of the kind noted here would soften the local and global environmental impacts of providing and using energy, including reductions in combustion emissions by raising the level of delivered energy services per unit of emissions. In fact, the environmental rationale may prove the most compelling if the magnitude of global climate change is as serious as some analysts predict. On this last point, achieving this scenario would limit the growth of U.S. CO_2 emissions 20 percent by 2015 relative to base scenario projections.

HIGH EFFICIENCY SCENARIO

This scenario incorporates many energy efficiency investments that are beyond the level at which life-cycle paybacks would be realized. This scenario, therefore, is more difficult to justify than the moderate efficiency scenario under current economic, security, and environmental conditions. For this scenario to become a national goal, extreme threats to energy security or the global environment would probably be necessary.

Serious climate change would probably serve as the strongest rationale. This scenario represents a major effort and investment to back out coal use. No new coal-fired generating capacity would be installed; new supply requirements would be covered by a combination of renewable, nuclear, and natural gas technologies. Some coal-fired plants are closed and carbon emissions at others are lowered by natural gas co-firing. Existing fossil fuel plants would have to be retired entirely after 40 years (rather than the typical 60). While the natural gas, renewables, and nuclear industries would grow slightly, the coal industry—and coal states in particular—would suffer abrupt economic declines unless adequate State and National contingency planning were conducted successfully in the short term.

Tax incentives (e.g., a 2- to 5-cent per kilowatt hour (kWh) credit for renewable electricity generation), accelerated plant depreciation schedules, and information programs could encourage the use of low- or no-carbon fuels, cogeneration, or help speed the retirement of coal-fired generating plants. However, in an aggressive demand-side effort such as this scenario implies, information programs and consumer-oriented financial mechanisms are less useful policy tools: more coercion than convincing or consumer financial assistance would be required. For example, eliminating the construction of new coal-fired capacity would be a basic regulatory requirement under this scenario. Moreover, the Government would have a major role in coordinating activities within and among the sectors to make the transition to such a highly energy efficient economy as smooth as possible, especially as the effects of such policy changes are likely to be substantial.

Higher taxes, aggressive efficiency standards, other regulatory changes (e.g., requirements disallowing the installation of new coal-fired generation capacity), and sustained, high levels of RD&D funding together would be the most valuable policy tools in such a scenario. In this regard, the high efficiency scenario would require an intensification of the same policies suggested in the moderate efficiency scenario. Accordingly, this scenario and the policies that would be needed to implement it are, for the most part, a major departure from the NES.

In combination with other policies, higher taxes would be essential, probably at least double the cost of energy, which would still leave U.S. energy prices lower than in some other countries. A carbon tax in the range of $75 to $150 per ton would encourage fuel switching and conservation. A tax of this magnitude would make natural gas more competitive than coal at many electricity generating facilities.[13] To offset the potential economic effects of increasing prices through energy taxes, the Federal Government could lower other taxes on individuals and firms.

High-efficiency standards would be a major part of this policy package. Buildings and appliances would be required to meet the highest efficiency now achievable. As a result of such standards, new residential units by 2015 could require 85-percent less heating and 45-percent less air conditioning than the average home today, and retrofits could be aggressively applied to all buildings such that their energy needs drop 30 percent. In the transportation sector, as part of an intensification of the other demand-curbing measures given in the moderate efficiency scenario, fuel economy standards for new autos would rise to 55 mpg (holding the current fleet size mix and performance characteristics constant). With a shift to smaller vehicles, which is likely with high fuel costs, the average fuel economy of the new car fleet could rise to 58 mpg by 2010. With standards this aggressive, the first costs for these consumer products are expected to increase, and consumer choice would be reduced, as fewer products would be available in the market that meet these tough standards, at least in the short term.

RD&D would be essential to expand the menu of available technological options. As noted, this scenario assumes that technologies expected to be available in 10 years are widely implemented by 2015. Expensive projects such as automobile engines and transmissions would have a high priority. The total estimated net cost of this high-efficiency package could be nearly as high as 1.8 percent of gross national product (GNP), or could result in a net savings of a few tenths of a percent of GNP. This compares with total current U.S. environmental GNP costs of 1.5 percent and the total current GNP costs of direct fossil fuel and electricity consumption of roughly 9 percent.[14]

A key part of a high-efficiency scenario is Federal Government energy use. In several ways, Government efficiency lags behind other sectors, which is not only expensive but diminishes credibility.[15] Use of standards, changes in procurement guidelines, and realistic energy performance goals are some of the major ways the Federal Government can reduce its energy use if policymakers determine that this should be a priority. Although specific changes in Government energy use are not a defined element in this scenario, such improvements would be necessary to achieve the goals outlined here.

In addition, the Government would need to increase expenditures for improving transportation and industrial infrastructure. Increased mass transit funding is assumed in this scenario to improve high-speed intercity rail systems enough to curb interurban car travel by 5 percent and air travel by 10 percent.

HIGH RENEWABLES SCENARIO

The high renewables scenario represents a major but less aggressive effort than the high efficiency scenario to back out coal use to reduce quickly CO_2 emissions. Implementing policies for a high level of renewables could be easier than efficiency measures, because the need to influence directly individual consumers would be reduced. In large part, the development of renewable energy sources—especially for electricity generation—would require policies targeting utilities and industry. Financial incentives could be the most important policy tool in this scenario, because each sector will require investments in technological supply options that simply are not competitive in current markets. Historically, tax incentives in particular have hastened the commercial availability of renewable technologies, and they appear to have had the added effect of encouraging private sector RD&D when

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[13] U.S. Congress, Office of Technology Assessment, op. cit., footnote 9, p. 26.

[14] U.S. Congress, Office of Technology Assessment, op. cit., footnote 9, pp. 10-11, 321.

[15] U.S. Congress, Office of Technology Assessment, op. cit., footnote 3.

Federal Government RD&D support sharply dropped beginning in 1982.[16]

As a result, the Government might consider tax credits, low-cost loans, or direct payments to subsidize the growth of solar, wind, and geothermal electricity generation, as well as the increased production of biomass fuels (such as ethanol for transportation). Accelerated capital depreciation schedules coupled with investment credits that favored renewables could also speed the wide-scale adoption of renewable supply technologies by encouraging their acquisition more quickly and easily than the market generally would by itself.

Financial incentives would clearly help correct the current inability of renewable energy sources to compete with fossil fuels, the sources that are currently cheaper (and that are likely to remain so in a price system that consistently fails to capture environmental externalities). To pay for such incentives, and to help create a level field between more expensive renewable and less expensive nonrenewable energy forms, some energy taxes could be established (e.g., carbon emissions) while others could be increased (e.g., gasoline). The combined effect of incentives and taxes has the potential to push the expansion of the renewable energy supply base further than either option would alone.

The most expeditious way of promoting large-scale, renewable energy use would be assured by direct regulatory intervention. If the use of renewable technologies to generate electricity, for instance, was favored as a first option by regulation, the need for additional incentives or energy taxes could possibly be eliminated.

The efficiency standards used in the moderate efficiency scenario are assumed to be implemented here. In addition, changes in the efficiency standards required of qualifying facilities (QFs) under the Public Utility Regulatory Policies Act of 1978 (PURPA), Public Law 98-617, could be made that would discourage the expansion of fossil-fuel-based generating capacity while promoting the adoption of more efficient and less polluting systems, e.g., cogeneration or IGCC technologies. A special category of PURPA qualifying facilities could be created that allowed more favorable treatment of generators that actually operated solely on renewable sources, but the contribution of such generators would probably be small (absent price or other regulatory incentives) in the timeframe of this scenario. Under our current regulatory system, merely increasing the PURPA size qualifications for QF status will have the effect of encouraging more gas-fired (rather than renewable source) electricity generation, because gas is the cheaper option. As it is currently written, PURPA grants QF status to many small, fossil-fired generators, which are commonly more efficient but not necessarily driven by renewable sources.

As suggested in the NES, efforts to expand hydropower would be eased if regulations governing siting, permitting, and environmental review were streamlined, but such regulatory changes could not simply cloak efforts to reduce or effectively eliminate adequate public review of the licensing process. The enhancement of existing hydropower capacity also is an important option.

To expand the market for alternative transportation fuels (whether produced from biomass, coal, or natural gas), their use as gasoline additives could be made required practice, but the environmental trade-offs would have to be evaluated. Similarly, the required use of alternative transportation fuels in U.S. fleets would increase their production and distribution but at an undetermined cost. At a minimum, their adoption in Federal fleets for all nonmilitary and select military use would be appropriate if the Government decided to promote or require their increased use.

RD&D is essential for this scenario. Many renewable technologies remain too expensive to compete with conventional fuel technologies, but many show considerable promise for improvement. In addition, intermittent energy sources, e.g., photovoltaics, solar thermal, and wind, will not develop as significant contributors to online electrical capacity until improved storage technologies are developed.

The high costs of this scenario, occurring at a time when conventional sources remain relatively inexpensive, suggest why the demand-side measures implemented in the moderate efficiency scenario are retained here to balance supply and demand forces together. Efficiency measures meeting the original condition of achieving life-cycle paybacks will help moderate the need for what are currently the more expensive energy sources (renewables).

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[16] An extended analysis and discussion of the role of financial mechanisms, e.g., tax incentives, to encourage renewable energy growth is contained in U.S. Congress, Office of Technology Assessment, *New Electric Power Technologies: Problems and Prospects for the 1990s*, OTA-E-246 (Washington, DC: U.S. Government Printing Office, July 1985). See especially pp. 290-294.

HIGH NUCLEAR SCENARIO

The high nuclear scenario assumes that a major commitment to nuclear power is deemed essential, most probably because of global climate change. As a result, this scenario exploits nuclear power as much to reduce coal combustion as to increase electricity production. Most coal plants would be retired to reduce U.S. CO_2 emissions, one-third of which currently derive from electricity generating plants. Unlike renewable sources, the amount of nuclear power capacity that is built in the coming decades depends more on political decisions and less on resource constraints or industrial capability.

Like the high renewables scenario, the high nuclear scenario assumes that expensive efforts to expand the supply base will be matched by the same level of demand-side controls called for in the moderate efficiency case. Thus, these three scenarios assume the same level of end-use energy demand by 2015, and the demand control options discussed in the moderate scenario would all apply here.

Reviving nuclear energy as a viable option would require a major change in public acceptance, which could be induced by serious global climate changes or intense Government efforts to improve the safety and public acceptance of this power source, such as imposing stricter standards on plant design and operations. In the absence of serious global climate change, Government efforts to revive public acceptance of nuclear power would mirror those mentioned in the high growth scenario: regulatory improvements, expedited waste disposal (including resolution of the national disposal facility issue), and expanded RD&D.

Previous Government and industry programs to improve public acceptance of nuclear power have had mixed results. To meet the high growth of nuclear capacity assumed here, these programs would need to demonstrate the safety and necessity of the new reactors. Nuclear technology and management have improved considerably, and controlled growth would present fewer risks to society than previously, but the case has to be made credibly.

As discussed under scenario 2 (high growth), a large part of the problem is waste disposal. Since this scenario envisions even faster growth, faster progress is necessary. Waste siting is difficult but must be done with sensitivity to local needs, addressing the technical difficulties is also urgent.

As noted in the high growth scenario, standardization of designs and stable licensing are crucial for a revival. Preapproval of designs, and perhaps sites, might be possible. However, it could be very damaging to public acceptance if a streamlined licensing process is viewed as steamrolling opposition.

In the short term, a revival of nuclear power does not depend on new reactor technology RD&D. Instead, good design, public acceptance, and implementation of existing technology are more important to achieve the sharp growth in nuclear generating capacity for this study period. RD&D will be more important over time. As noted in chapter 4, current light water reactor technology may not be adequate if hundreds of reactors are installed. Even if it is, the economic advantages in diversifying design approaches would probably outweigh the costs of developing new reactors, e.g., the high-temperature gas reactor. In this regard, a decision is to be made in 1991 on which technology will be used for the tritium production reactor for the weapons program. This report has not examined the question of which technology is best for production, nor does it recommend which technology should be used in that military application. However, it is clear that the decision over which technology is used for military tritium production could have implications for civilian nuclear energy supply options in the future, particularly if the gas reactor technology is used. R&D will also be important in resolving the remaining safety issues, waste disposal, enrichment, and other areas.

COMPARING SCENARIOS

The six scenarios used in this report contain different assumptions about economic growth, energy supply and demand, and environmental constraints that the U.S. could face in the period 1989-2015. The scenarios are not meant as predictions, nor do they contain all the potential elements of what our energy future may look like. However, the varying assumptions in the scenarios are a collection of plausible outcomes. Because the scenarios vary greatly, the best policy packages for achieving them vary as well. As a result, comparing the major features of the scenarios will convey their relative merits and suggest which policies could be the most appropriate or valuable in the future. The policy issues most relevant to all scenarios (except the baseline) are summarized in table 5-1.

Scenarios 4, 5, and 6 are extreme outcomes based on the growing chance of an extreme problem: global climate change. These scenarios rapidly reduce the use of coal in electricity generation, despite our large resource base, in order to reduce CO_2 emissions. A somewhat different package of such extreme policy measures could be warranted if severe threats to energy security develop. The cost of implementing any of these three scenarios could be high, but the cost of not implementing them if global climate change proves as disrupting as some analysts predict would be higher.[17]

Scenarios 4, 5, and 6 assume that major policy decisions and Federal budget commitments are made long before the problem that would precipitate these changes—serious climate change—is likely to occur. This fact, however, does not diminish the value of considering these scenarios, their policy requirements, and their effects to counter global climate change (or severe threats to energy security); it merely postpones their provable urgency. Our current understanding of the lagtime in atmospheric responses to changes in trace gas concentrations, e.g., CO_2, suggests that the urgency of making policy decisions similar or identical to the last three scenarios could be appropriate now.

The base case requires no policy changes. It assumes no major changes in environmental conditions (e.g., global climate change), U.S. energy supply security, and U.S. energy demand growth. This future is plausible but risky. At a time when U.S. production of natural gas and oil has slowed or dropped, political stability in the Middle East is as uncertain as ever, the prospects for large contributions from alternative and renewable energy supplies are on a capricious and lingering threshhold, and the steady buildup of atmospheric CO_2 continues unabated, the probability that the availability, price, and supply of oil fuels will all remain stable is not high.

Scenario 2 is even more optimistic. That scenario assumes that continued fossil fuel use will not be curbed by domestic or international concerns about global climate, that fossil fuel reserves will actually expand, and an uninterrupted level of economic growth not seen in two decades will be fueled by abundant and relatively inexpensive energy.

Scenario 3 is a moderate effort to curb U.S. energy demand, but it would require an unprecedented use of cost-effective investments and success in energy efficiency and conservation. Though it requires less extreme measures than the high-efficiency measures in scenario 4, it would still require a prodigious effort by Government and citizens to be realized.

Scenario 4 adopts the same approach as scenario 3 (demand control), but its measures and outcome are more extreme. This is the only scenario that actually results in *lower* total energy demand at the end of the study period. Such an outcome would require many investments in energy efficiency that would exceed life-cycle paybacks suggesting that extreme threats to the global environment or energy security would be necessary to impose policy measures this economically severe.

Scenarios 5 and 6 entail aggressive supply-oriented measures, but they exploit the same level of demand-side measures as scenario 3 and thus provide an illustrative lesson about mixing supply and demand-side measures in an energy policy.

Any of these scenarios could be the right choice depending on the resolution of several critical but presently unknowable factors. In particular, the specter of climate change could invalidate the first three scenarios, technical developments could make the last three much more feasible, and unexpected resource discoveries could lead to the high growth of scenario 2. Prudent policymaking will protect society against negative outcomes while maximizing the possibility of positive developments. The value judgments and risk assessments that determine the decisionmaking ultimately guiding the country along its actual path are beyond the scope of this report. It is hoped that the above discussion provides a background for understanding where decisions about the nation's energy future fit in the overall context of the national goals of economic well-being, environmental quality, and security.

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[17] As mentioned earlier, the estimated net cost of the high efficiency scenario alone could be a positive several tenths of 1 percent of GNP to as much as a negative 1.8 percent of GNP. Depending on its magnitude, the cost of climate change could be as great or greater; it could also be lower.

Table 5-1—Summary of Policy Options

Scenario	Financial mechanisms	Taxes	Info management	RD&D	Standards	Federal programs
High growth	Credits, loans and payments for synfuels; tradable permits for coal emissions; incentives for electric vehicles.	No change from baseline scenario.	No change from baseline scenario. Improve public acceptance of nuclear power.	Clean coal technologies; advanced oil and gas recovery; synfuels; fluidized bed and IGCC; electric vehicles.	No changes needed in energy performance standards; emissions reductions in utility and transportation sectors probably necessary.	PURPA/PUHCA revisions to expand resource base, increase competition; eased plant siting to keep costs down; OCS/ANWR opened; SPR increased; improved nuclear licensing and waste disposal facility.
Moderate efficiency	Tax credits and accelerated depreciation for quicker equipment turnover; tradable permits for emissions reductions, (industry and utilities), coupled with tougher emissions standards.	Energy taxes; gasoline tax in the range of 50 cents; other energy taxes raised accordingly; carbon tax of at least $75 to $150/ton; added taxes on inefficient equipment.	Increase Government and utility efforts to impart life-cycle opportunities (retrofits & new equipment).	Vigorous for all sectors.	Raise building and equipment performance standards (NAECA, BEPS); CAFE to 39 mpg; tradable permits; 55-mph speed limit; HOVs and carpooling programs; and utility demand-side management programs.	Aggressive FEMP; increased funding for urban/intercity rail; Federal procurement and technology transfer are key.
Tough efficiency	Similar to moderate efficiency scenario, but at a higher level.	Energy taxes and especially carbon taxes of at least $150/ton; purchase taxes that levelize prices of equipment with varying efficiencies.	Same as moderate efficiency scenario.	Extremely aggressive; technologies available by 1999 implemented by 2015.	CAFE 55 mpg; most energy efficient design for buildings and equipment; stronger utility emissions reductions; ban new coal-fired generating plants.	Aggressive retirement of coal plants; natural gas cofiring; stronger DSM programs; aggressive FEMP; high national priority tied to infrastructure funding.
High renewable	Renewable investment tax credits for electricity generation & biomass fuels production; low-cost loans; accelerated capital depreciation for existing fossil-powered systems; same demand controls as moderate efficiency scenario.	Energy taxes on fossil fuel use only; carbon taxes as an alternative; same as moderate efficiency scenario.	Same as moderate efficiency scenario.	Especially for storage technologies.	Same as moderate efficiency plus standards for generating plants that favor renewables.	Favorable regulatory treatment encouraging renewables; fleet use of alternative fuels; extended and improved hydro (existing capacity).
High nuclear	Accelerated depreciation schedules for utilities committed to investing in nuclear plants; investment tax credits for new nuclear construction; same demand controls as moderate efficiency scenario.	Large carbon tax on utilities to encourage nuclear growth.	Same as moderate efficiency scenario. Improve public acceptance of nuclear power.	RD&D needed for advanced reactor designs; modular components; waste disposal technologies.	Same as moderate efficiency; also higher standards for non-nuclear plants.	Streamlined licensing; waste disposal facility.

ABBREVIATIONS: BEPS = Building Energy Performance Standards; CAFE = Corporate Average Fuel Economy Standards; DSM = Demand-Side Management; FEMP = Federal Energy Management Program; HOVs = High Occupancy Vehicle lanes; IGCC = Integrated Gasification Combined Cycle; NAECA = National Appliance Energy Conservation Act; OCS/ANWR = Outer Continental Shelf/Arctic National Wildlife Refuge; PURPA/PUHCA = Public Utility Regulatory Policies Act/Public Utility Holding Company Act; RD&D = Research, Development, and Demonstration; SPR = Strategic Petroleum Reserve

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